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DEVELOPMENT OF IMPROVED WIDE TEMPERATURE RANGE ARCTIC ENGINE OIL (OEA-30)

INTERIM REPORT
TFLRF No. 309

By
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The technical feasibility of developing an improved, multifunctional arctic engine oil for U.S. military ground mobility equipment was investigated. The concept was proven feasible, and the new oil was designated as OEA-30. The current arctic engine oil (MIL-L-46167B) is qualified at 22 percent derated conditions in a two-cycle diesel engine test. OEA-30 has exceptional two-cycle diesel engine performance at full engine output and can be operated beyond the 5°C (40°F) maximum ambient temperature limit of the current arctic oil. Multifunctional requirements of OEA-30 were achieved by including selected portions of Allison Transmission Division C-4 and Caterpillar TO-4 specifications. The most promising OEA-30 candidate was reformulated to American Petroleum Institute (API) CG-4 performance level and will be further evaluated in a follow-on program.

14. SUBJECT TERMS

Arctic Oil	Engine Oil	Two-Cycle Diesel
MIL-L-46167B	Diesel Engine	C-4
MIL-L-2104F	Engine Lubricant	TO-4

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EXECUTIVE SUMMARY

Problems: Current arctic engine oil (MIL-L-46167B), designated OEA, has an upper ambient temperature use limit of 5°C (40°F), and two-cycle diesel engine performance is defined under 21.7 percent derated conditions. In addition, operation at higher ambient temperatures is deficient in hydrostatic transmissions. The vehicle is not able to pull full-load because of internal fluid leakage related to the very low viscosity of the OEA. An oil with improved two-cycle diesel engine performance and improved hydrostatic transmission performance beyond 5°C is desired.

Objective: The objective of the project was to develop a new U.S. Army diesel engine lubricant for inclusion in MIL-L-2104 which will replace the current arctic engine oil. The new oil will have a viscosity designation of OEA-30 and is intended for use in diesel engines powershift and hydrostaic transmissions, at ambient temperatures ranging from arctic to desert conditions.

Importance of Project: The successful completion of this project will provide the U.S. Army with an arctic engine oil that has improved two-cycle diesel engine and hydrostatic transmission performance and can be used at a higher ambient temperature than the current product. The new OEA-30 will be multifunctional in that it will be used in power transmission appplications for military tactical/combat ground equipment. New OEA-30 will reduce oil usage via elimination of seasonal change in areas where OEA is required for a portion of the year.

Technical Approach: The technical approach was to develop the requirements for OEA-30. Oil/chemical companies were requested to supply candidate oils for evaluation. The most challenging technical obstacle was to achieve satisfactory two-cycle diesel performance at full rated output. Because the two-cycle diesel engine family is extremely sensitive to oil viscosity/volatility, careful balancing of the synthetic basestocks was required. Two-cycle diesel engine performance and power transmission fluid test requirements were investigated using candidate OEA-30 oils.

Accomplishments: The technical feasibility of developing an improved, multifunctional arctic engine oil for U.S. military ground mobility equipment was investigated. The concept was proven feasible, and the new oil was designated as OEA-30. A candidate OEA-30 had exceptional two-cycle diesel engine performance at full engine output, and can be operated beyond the 5°C (40°F) maximum ambient temperature limit of the current arctic oil. Multifunctional requirements of OEA-30 were achieved by including selected portions of Allison Transmission Division C-4 and Caterpillar TO-4 specifications. The most promising OEA-30 candidate was reformulated to API CG-4 performance level and will be further evaluated in a follow-on program.

Military Impact: Successful fielding of this new lubricant will result in reduced logistical burdens and allow the cancellation of MIL-L-46167B. The military can expect to achieve improved readiness through less seasonal oil drains because of the expanded upper temperature use limit of the OEA-30 oil. There will be the environmental impact of less used oil to be disposed.

FOREWORD/ACKNOWLEDGMENTS

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I. INTRODUCTION AND BACKGROUND

Current U.S. Army arctic engine oil requirements are defined by Military Specification MIL-L-46167B.(1)* The lubricating oil covered by MIL-L-46167B is intended for the crankcase lubrication of reciprocating spark-ignition and compression-ignition engines used in all types of ground equipment under all conditions of service, as defined by appropriate lubrication orders, when ambient temperatures are in the range of 5 to –55°C. However, it is not to replace Grade 10W, MIL-L-2104F (2) lubricant in areas where ambient temperatures are above –25°C. In addition, the lubricating oil governed by MIL-L-46167B is intended for use in arctic regions as an all-weather, year-round power transmission fluid for military tactical/combat ground equipment.(1)

The arctic engine oil currently in use has the following limitations:

1) the upper ambient temperature use limit is 5°C (40°F);

2) two-cycle diesel engine performance is defined under 21.7 percent derated power conditions.

II. OBJECTIVE AND APPROACH

The objective of this program is to develop a new U.S. Army diesel engine lubricant for inclusion in Military Specification MIL-L-2104 as a replacement for the current arctic engine oil MIL-L-46167B. The new oil will have a viscosity designation of OEA-30 and is intended for use in diesel engines and powershift and hydrostatic transmissions at ambient temperatures ranging from arctic conditions to 48.9°C (120°F). Oil meeting MIL-L-46167B requirements has the following typical low-temperature viscosities:

* Underscored numbers in parentheses refer to the list of references at the end of this report.

Temperature, °C	Kinematic Viscosity, cSt
–20	1,000
–30	2,750
–40	8,600
–50	34,500
–55	79,850

The proposed OEA-30 oil will have low temperature viscometric properties that are slightly relaxed from MIL-L-46167B but superior to commercially available Society of Automotive Engineers (SAE) 0W-30 oils. Compared to MIL-L-46167B oil, the OEA-30 oil may have a 10°F higher operability temperature limit at very low temperature conditions. The targeted physical properties requested for the OEA-30 candidate oils were as follows:

Kinematic viscosity, cSt	
–40°C	16,000 max.
100°C	9.3 to 12.5
Pour point, °C	–50 max.
High temperature, high shear viscosity, 150°C, cP	3.2 to 3.7

The following MIL-L-2104F performance requirements were identified for the OEA-30 grade:

- Full two-cycle diesel engine performance (power output not derated);
- Four-cycle diesel engine performance determined by
  - Caterpillar 1-K test
  - Mack T-7 test;
- Oil oxidation resistance and antiwear properties determined by American Society for Testing and Materials (ASTM) Sequence III E test;
- Bearing corrosion resistance determined by ASTM CLR L-38 test;

- Transmission performance tests selected from Allison C-4 and Caterpillar TO-4 specifications.

Later in the program, the performance requirements were modified to include new American Petroleum Institute (API) CG-4 requirements for four-cycle diesel engine performance.(3)

The U.S. Army will realize the following advantages from the OEA-30 oil:

- OEA-30 oil can be used at much higher ambient temperatures than the current arctic engine oil, which will result in fewer seasonal oil changes.

- OEA-30 oil will improve readiness and reduce the quantity of used oil which must be disposed of in an environmentally safe manner.

- A reduced logistics burden will result from the cancellation of Military Specification MIL-L-46167B.

- An improvement will be seen in two-cycle diesel engine performance with a significantly increased margin of protection.

III. DISCUSSION

A. Candidate Lubricants

Five candidate oils from three different companies were evaluated in this program. TABLE 1 provides oil identifications, designations, viscosity grades, and a description of each candidate oil. Properties of the five candidate oils are presented in TABLE 2. Each candidate contained zinc and phosphorus additive elements, indicative of the presence of zinc dithiophosphate multifunctional antiwear additive.

TABLE 1. Description of Candidate Oils

Oil Identification	Oil Designation	Viscosity Grade	Description
AL-18930	A	SAE 0W-30	Commercial oil, Company A
AL-19660	A1	OEA-30	Experimental oil, Company A
AL-20483	A2	OEA-30	Experimental oil, Company A
AL-19528	B	OEA-30	Experimental oil, Company B
AL-19392/19547	C	SAE 0W-30	Commercial oil, Company C

TABLE 2. Properties of Candidate Oils

Oil Identification, AL- Oil Designation	18930 A	19660 A1	20483 A2	19528 B	19392/19547 C
Lubricant Analyses/Performance					
Kinematic Viscosity, cSt					
–40°C	Solid	16,483	18,415	14,517	26,463
40°C	57.48	53.20	52.23	54.78	48.12
100°C	10.70	9.99	10.05	11.01	10.46
Viscosity Index	180	178	183	198	214
Apparent Viscosity, cp, CCS at –30°C	2,650	3,250	3,300	2,850	2,270
Apparent Viscosity, cp, MRV at –35°C	ND*	7,990	<10,000	6,998	6,420
High Temp., High Shear Vis., cp, 150°C, D 4624	3.21	3.22	3.35	3.08	2.97
Flash Point, °C	ND	238	251	221	213
Pour Point, °C	–40	ND	<–60	<–55	–54
Sulfated Ash, wt%	1.1	1.1	1.02	0.95	1.11
TAN	2.6	2.2	2.3	2.6	2.6
TBN, D 664 (D 4742)	6.7	6.0	(8.9)	6.4	7.9
Elements					
S, %, XRF	0.37	0.3	0.35	0.3	0.32
ICP, ppm					
Ca	1,901	1,795	1,780	2,372	2,900
Mg	650	649	709	6	1
B	<1	4	1	164	345
P	954	981	1,076	1,045	1,075
Zn	1,029	1,050	1,228	1,080	1,234
Cu	ND	<1	<1	<1	<1
N, %	0.06	0.07	0.09	ND	0.06

* ND = Not determined

Three candidate oils were from Company A. Oil A was a commercially available SAE 0W-30 viscosity grade product. The basestocks of Oil A were polyalphaolefin (PAO) material. Unfortunately, Oil A had inadequate low temperature characteristics and was a solid at –40°C. Oil A had a sulfated ash content of 1.1 wt%, a total base number (TBN) of 6.7 by ASTM D 664 (4), and contained calcium-magnesium detergent-dispersant additive system chemistry. Oil A1 contained a basestock blend of PAO and polyolester (PE) materials. Kinematic viscosity of Oil A1 at –40°C was 16,483 cSt. Additive package chemistry was similar to that of Oil A. Oil A2 contained a revised blend of PAO and PE basestock materials and an additive package similar to those of Oils A and A1. The kinematic viscosity of Oil A2 at –40°C was 18,415 cSt.

Company B submitted one candidate oil. Oil B contained a basestock blend of PAO and ester materials and had a kinematic viscosity at –40°C of 14,517 cSt. It had a sulfated ash content of 0.95 wt% and contained a calcium-based detergent-dispersant additive system with a TBN of 6.4 (D 664).

Candidate Oil C from Company C was a commercially available product (API SG/CD) that met the requirements for viscosity grade SAE 0W-30. Oil C contained a blend of petroleum and PAO basestocks and had a kinematic viscosity at –40°C of 26,463 cSt. It had a sulfated ash content of 1.1 wt% and contained a calcium-based detergent-dispersant additive system with a TBN of 7.9 (D 664).

Projected oxidation resistance of each candidate oil was determined by the Thin Film Oxygen Uptake Test (TFOUT) (ASTM D 4742).(5) Results for the five candidate oils are illustrated in Fig. 1. Each candidate oil had excellent TFOUT performance with breakpoints in excess of 200 minutes, which indicates that all candidates had excellent oxidative stability.

Deposit-forming tendencies of the candidate oils were determined using a LUBTOT device.(6) A schematic of the LUBTOT apparatus is presented in Fig. 2. In this test, oil is flowed around a heated aluminum tube, and the resulting tube deposit volume is measured using a deposit

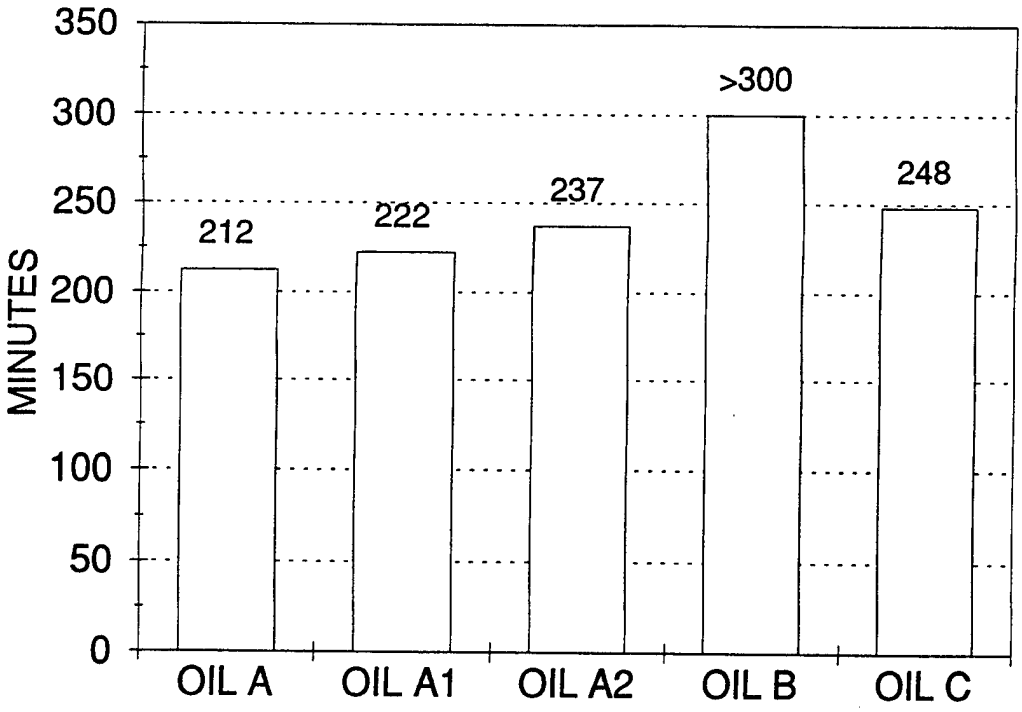

Figure 1. TFOUT results for five candidate oils

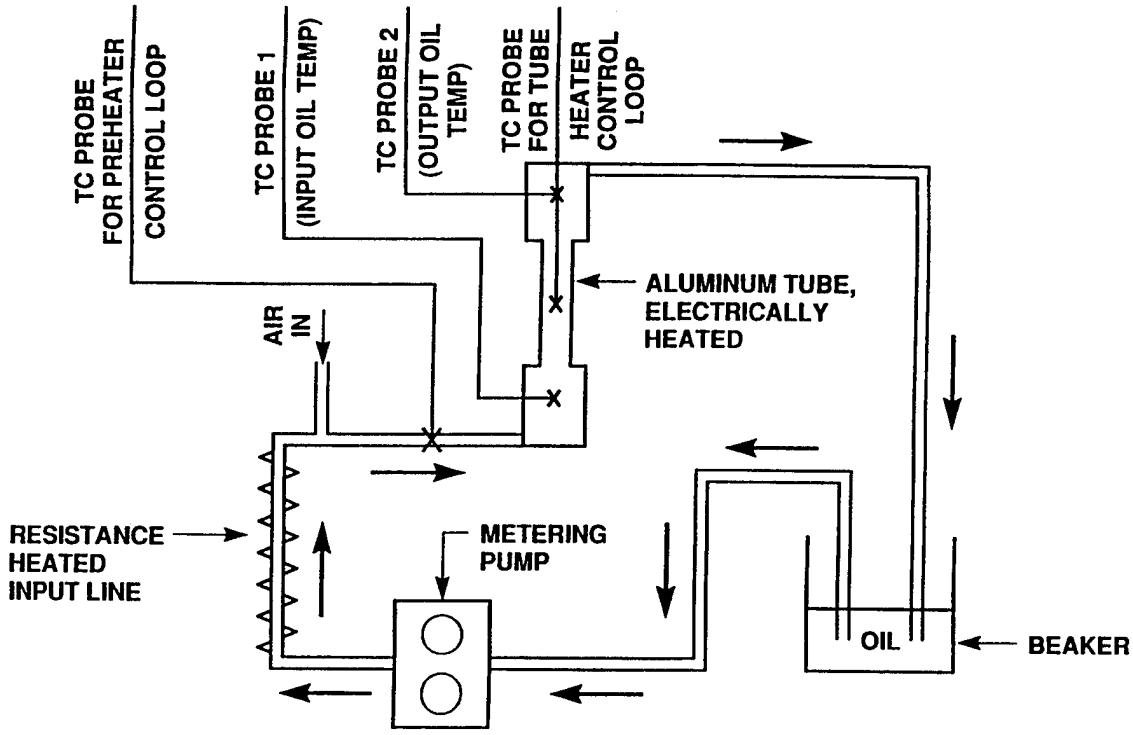

Figure 2. Schematic of the LUBTOT apparatus

measuring device.(7) The results of the LUBTOT tests conducted at 316°C aluminum tube temperature are presented in Fig. 3. The results for a low deposit Caterpillar 1-G2 reference oil (REO-203) and a high deposit reference oil (REO-191) are presented for comparison. Only Oil B gave a deposit volume that fell between the two reference oils. Oils A, A1, and C had much greater deposit volumes than the high deposit reference oil in this test. Results from this bench test indicate that piston deposits in four-cycle heavy-duty diesel applications are a potential problem for three of the candidate oils.

Volatility of the candidate oils was determined by a gas chromatographic boiling point distribution method. This method is a high temperature modification of ASTM D 2887 (8) that uses wall-coated open tubular column technology and has an upper limit of C-100 (720°C). TABLE 3 contains the summarized boiling point distribution data for the candidate oils, while Figs. 4 through 8 show the chromatograms. Overall, Oil A2 was the least volatile of the candidate oils, while Oil C had the greatest volatility. Comparison against industry passenger car engine oil volatility requirements provides a reference point for the volatility characteristics of these candidate oils. Industry uses limits on the maximum amount off at 371°C to control engine oil volatility. Oils A, A1, A2, and B have excellent volatility properties and meet the most restrictive requirement (10 percent maximum at 371°C) for SAE 40 grade oils. Oil C meets the most severe volatility requirements (17 percent at 371°C) for SAE 10W-30 passenger car motor oils.

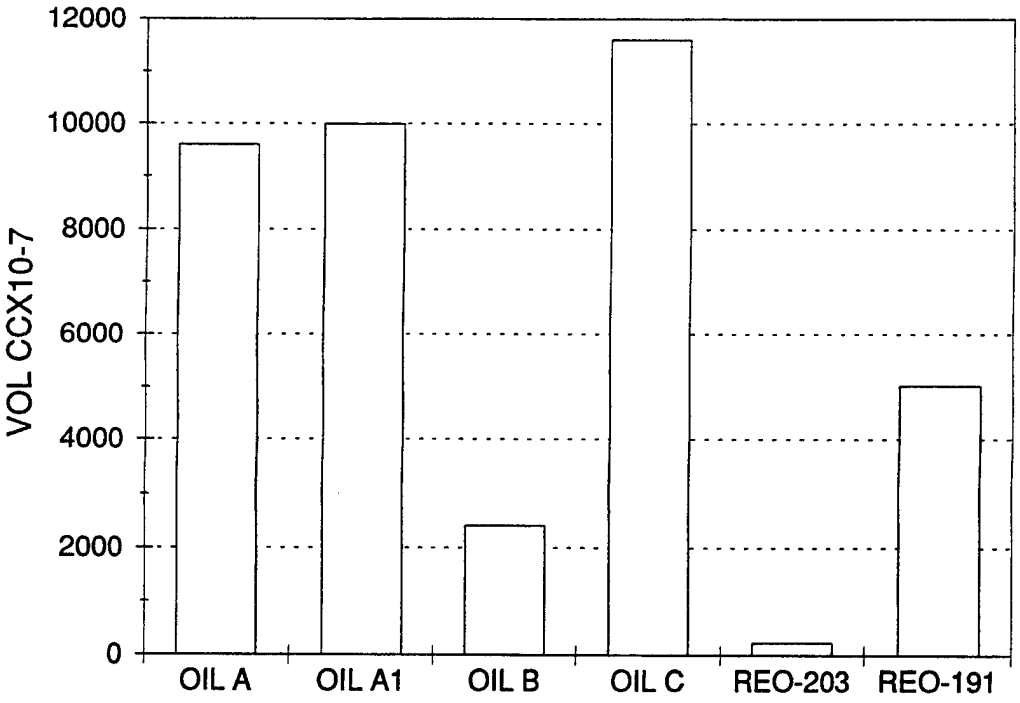

Figure 3. Results of LUBTOT tests conducted at 316°C

TABLE 3. Boiling Point Distribution
(ASTM D 2887 Modified for High Temperature)

Oil Identification, AL- Oil Designation	18930 A	19660 A1	20483 A2	19528 B	19392 C
% Off at °C					
Initial Boiling Point	294	284	319	308	296
5	365	379	384	381	341
10	398	410	413	406	358
15	412	417	419	413	370
20	417	420	422	416	381
30	421	425	430	420	404
40	426	431	455	423	416
50	430	468	474	428	421
60	437	477	478	431	425
70	478	485	487	443	430
80	488	489	490	480	446
90	548	528	528	575	524
95	641	594	589	648	622
Final Boiling Point	718	717	718	718	717

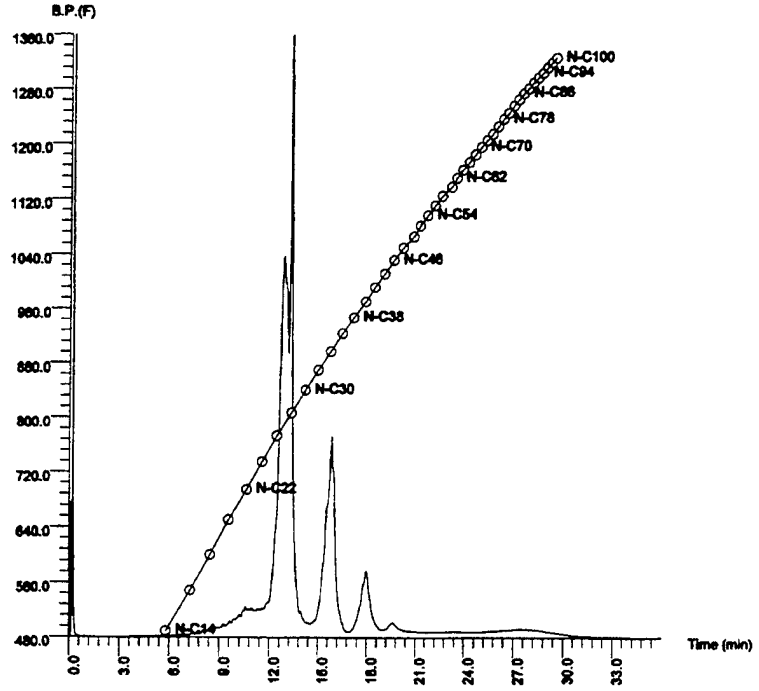

Figure 4. Gas chromatogram for Oil A

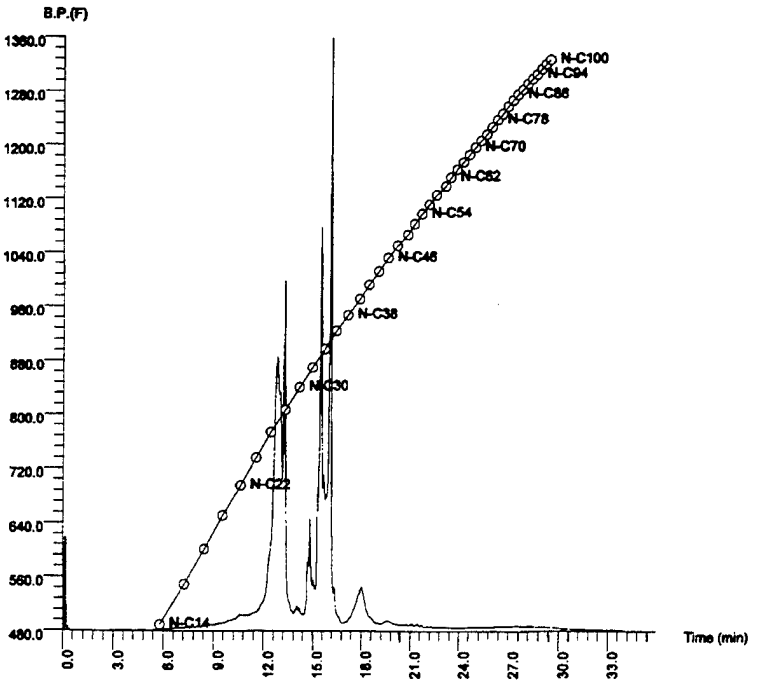

Figure 5. Gas chromatogram for Oil A1

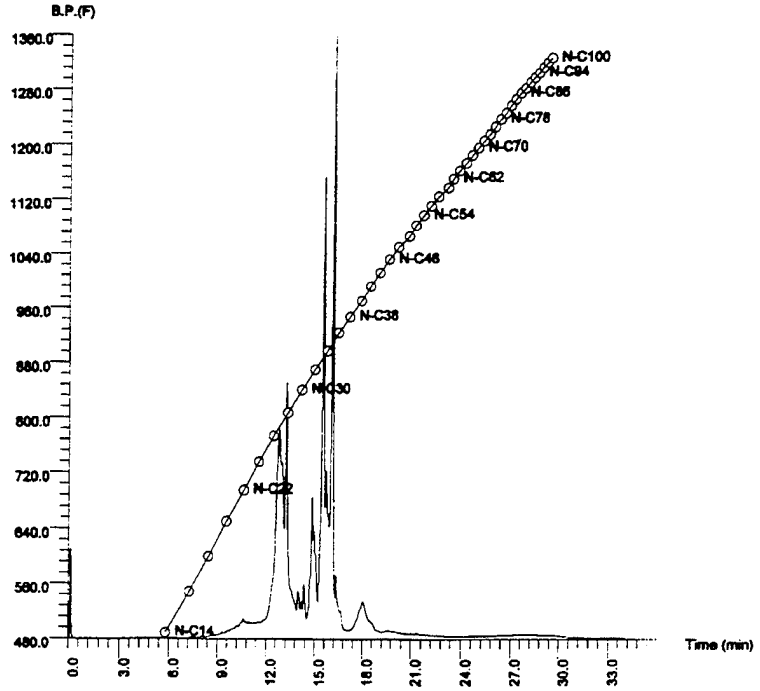

Figure 6. Gas chromatogram for Oil A2

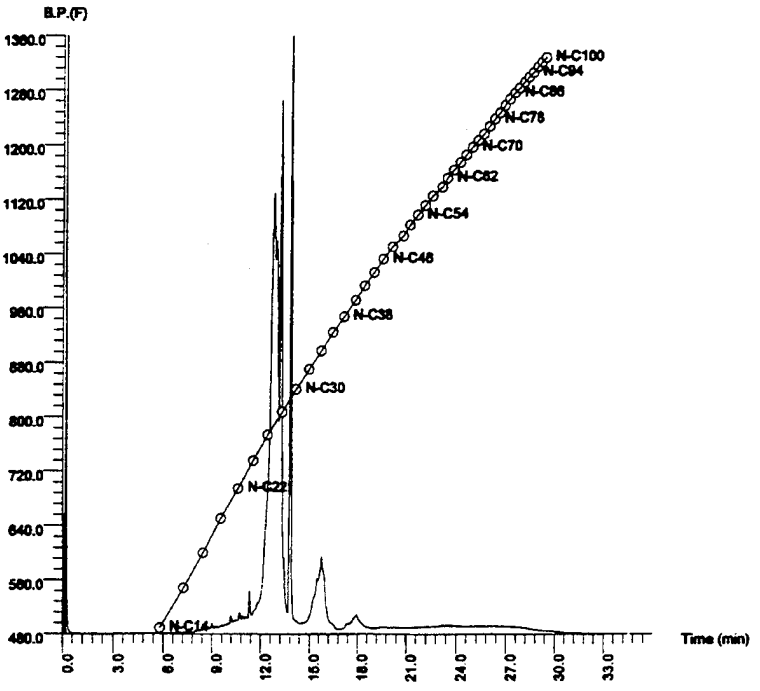

Figure 7. Gas chromatogram for Oil B

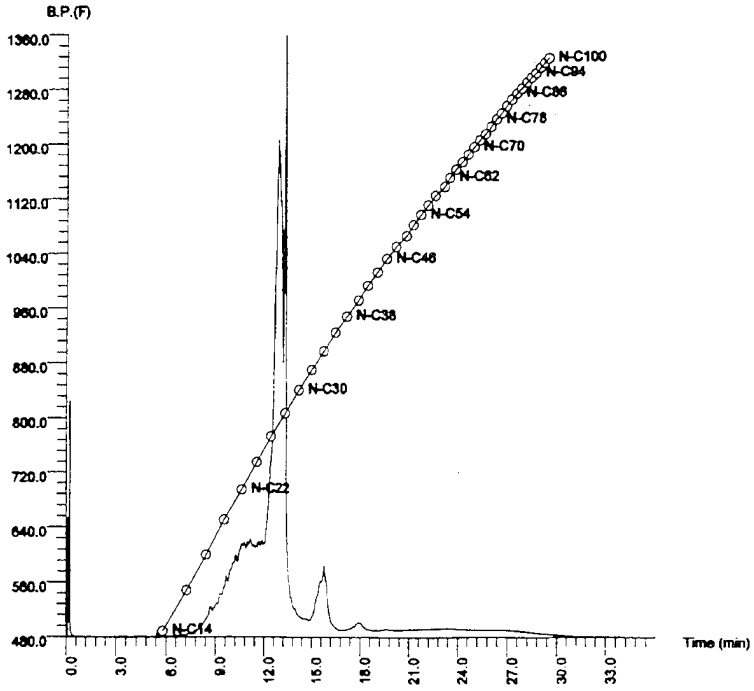

Figure 8. Gas chromatogram for Oil C

B. Two-Cycle Diesel Engine Performance

Two-cycle diesel engine performance is defined in the current specification for arctic engine oil, MIL-L-46167B (1), using Method 354.1 of Federal Test Method (FTM) Standard No. 791C (9). In Method 354.1, engine performance is conducted at 21.7 percent derated power condition from Method 355 (Army 240-Hour Tracked Vehicle Endurance Cycle). The 21.7 percent derated conditions were defined during a correlation study conducted in 1983.(10) The U.S. Army desired to upgrade the performance of OEA and extend its upper temperature use limit. The objective of this program was to determine the feasibility of operating at the full (nonderated) conditions of Method 355 using an improved arctic engine oil designated OEA-30.

1. Test Engine

The Detroit Diesel Corporation (DDC) 6V-53T two-cycle diesel engine was used to determine OEA-30 candidate oil performance. This engine has proven sensitive to oil volatility and viscosity considerations.(11) A description of the DDC 6V-53T engine is presented in TABLE 4, and a photograph of the engine dynamometer installation is shown in Fig. 9.

TABLE 4. DDC 6V-53T Engine Specifications

Model:	5063-5395
Engine Type:	Two-Cycle, Compression Ignition, Direct Injection, Turbo-Supercharged
Cylinders:	6, V-Configuration
Displacement, L (in.^{3}):	5.21 (318)
Bore, cm (in.):	9.8 (3.875)
Stroke, cm (in.):	11.4 (4.5)
Compression Ratio:	18.7:1
Fuel Injection:	DD Unit Injectors, N-70
Rated Power, kW (bhp):	224 (300) at 2,800 rpm
Rated Torque, Nm (ft-lb):	858 (633) at 2,200 rpm

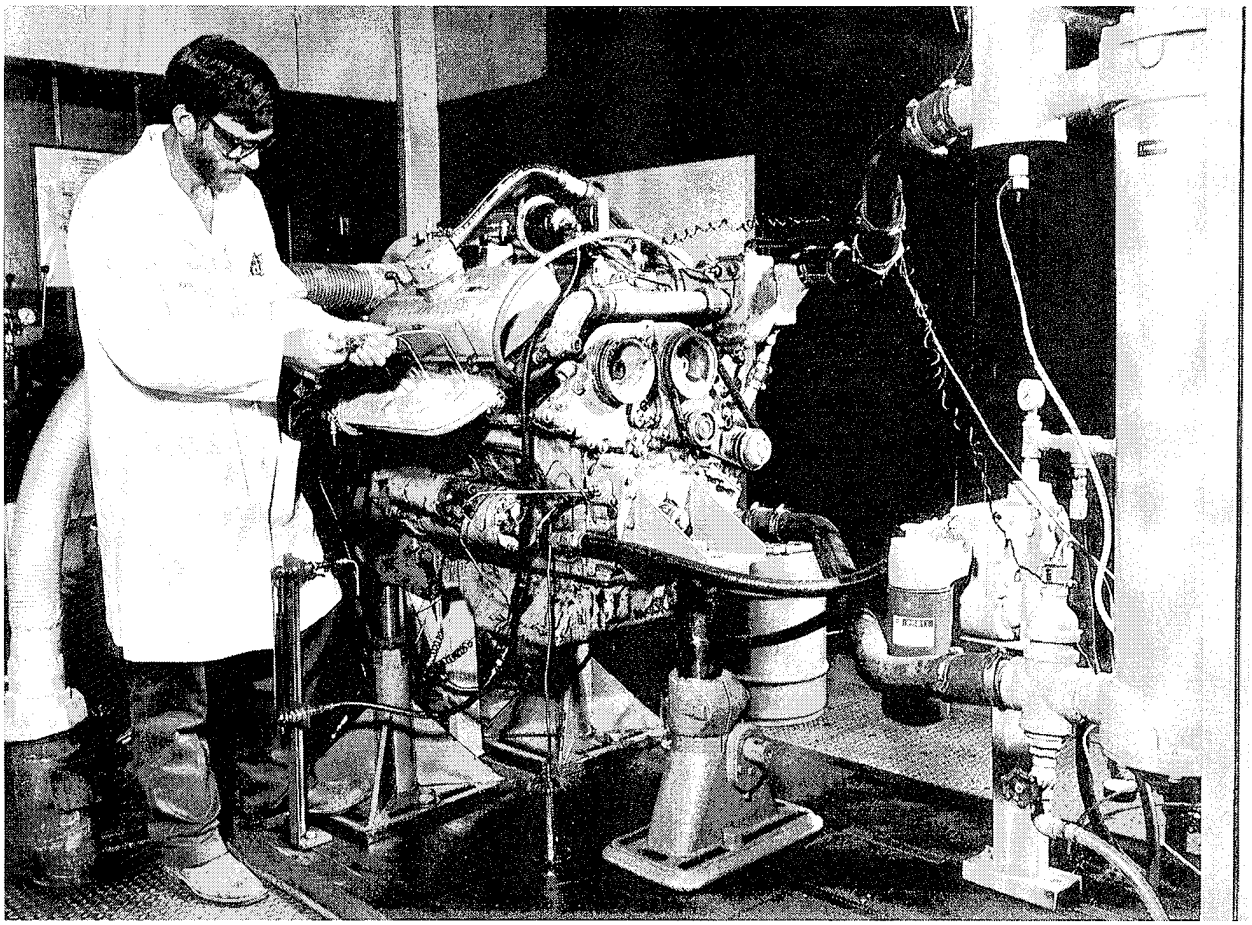

Figure 9. DDC 6V-53T engine installation

2. Test Fuel

The test fuel was Reference No. 2 diesel fuel supplied by a Texas refinery. The specification requirements for this fuel, commonly referred to as "Cat fuel," are set forth in Section 5.2, Methods 354 and 355 of FTM Standard No. 791C.(9) This test fuel is a straight-run, mid-range natural sulfur fuel manufactured under closely controlled refinery operation to minimize batch-to-batch compositional and physical property deviations. Properties of the test fuel are given in TABLE 5.

TABLE 5. Test Fuel Analysis

Properties	ASTM Method	Reference No. 2 Diesel Fuel	
		Test Fuel	Specification*
Gravity, API°	D 287	34.5	Record
Viscosity, cSt, at 38°C (100°F)	D 445	3.3	1.6 to 4.5
Flash Point, °C (°F)	D 93	85 (185)	37.8 (100) min.
Cloud Point, °C (°F)	D 2500	–2.0 (+28)	Record
Pour Point, °C (°F)	D 97	–12 (+10)	–6.7 (+20) max.
Water and Sediment, vol%	D 1796	0.0	0.5 max.
Carbon Residue, wt%	D 524	0.10	0.20 max.
Sulfur, wt%	D 129	0.41	0.35 min.
Acid No., mg KOH/g	D 664	0.0	Record
Aniline Point, °C (°F)	D 611	63 (145)	Record
Copper Corrosion	D 130	1A	No. 2 max.
Distillation, °C (°F)	D 86		
Initial Boiling Point		207 (405)	Record
10%		241 (465)	Record
50%		273 (524)	260 (500) min.
90%		317 (603)	316 to 338 (600 to 640)
End Point		348 (658)	343 to 366 (650 to 690)
Cetane No.	D 613	52	0 to 45
Net Heat of Combustion, MJ/kg (Btu/lb)	D 240	42.13 (18,130)	Record
Ash, wt%	D 482	0.006	0.01 max.

* ASTM STP 509A, Part I and II, Appendix F

3. Test Cycle

The engine dynamometer test cycle used to evaluate candidate oils was the Army/Coordinating Research Council (CRC) 240-Hour Tracked Vehicle Endurance Cycle, Method 355 of FTM 791C (9). This test cycle has been correlated to 6,437 kilometers (4,000 miles) of proving ground operation.(12) The test cycle, which alternates between idle, maximum power, and maximum torque, is detailed in TABLE 6. The operating conditions and limits for Method 355 are presented in TABLE 7.

TABLE 6. Army/CRC 240-Hour Tracked Vehicle Endurance Cycle (FTM 791C Method 355)

Period*	Time, hr	Rack/Setting
1	0.5	Idle
	2.0	Maximum power
	0.5	Idle
	2.0	Maximum torque
2	0.5	Idle
	2.0	Maximum power
	0.5	Idle
	2.0	Maximum torque
3	0.5	Idle
	2.0	Maximum power
	0.5	Idle
	2.0	Maximum torque
4	0.5	Idle
	2.0	Maximum power
	0.5	Idle
	2.0	Maximum torque
5	4	5-min idle, followed by shutdown

* These five periods yield 20 hours of running with a 4-hour shutdown; this cycle is repeated 12 times for a total test time of 240 hours.

TABLE 7. Operating Conditions for FTM 791C, Method 355

Operating Condition	Limits		
	Maximum Power Mode	Maximum Torque Mode	Idle Mode
Speed, rpm	2,800 ± 10	2,200 ± 10	1,000 ± 10
Fuel Flow, kg/hr (lb/hr)	53 (117), min.	44 (96), min.	NS*
Obs bhp Output	300 ± 5	265 ± 5	20 ± 5
Jacket-Out, °C (°F)	76.7 ± 1 (170 ± 2)	76.7 ± 1 (170 ± 2)	76.7 (170), max.
Coolant Temp., °C (°F)	4–7 (8–12)	4–7 (8–12)	NS
Inlet Air, °C (°F)	32 ± 2 (90 ± 5)	32 ± 2 (90 ± 5)	NS
Oil Sump, °C (°F)	121 (250), max.	121 (250), max.	NS
Oil Gallery, °C (°F)	100 ± 1 (212 ± 2)	95 ± 1 (203 ± 2)	79 ± 1 (175 ± 2)
Fuel Temp. at Filter, °C (°F)	35 ± 1 (95 ± 2)	35 ± 1 (95 ± 2)	NS
Fuel Pressure, gage kPa (psig)	241–483 (35–70)	241–483 (35–70)	NS
Compressor Suction, clean filter, cm (in.) water	20 (8), max.	NS	NS
Compressor Suction, dirty filter, cm (in.) Hg	25 (10), max.	NS	NS
Exhaust Back Pressure (after turbo), cm (in.) Hg	3.0–5.1 (1.5–2.0)	NS	NS
Blowby Pressure, cm (in.) water	10 (4.0), max.†	NS	NS
Oil Pressure, kPa (psig)	207 (30), min.	207 (30), min.	34 (5), min.

* NS = Not Specified

† Blowby pressure greater than 10 cm (4 in.) of water constitutes test shutdown for inspection.

4. Reference Run

The test cell installation was standardized prior to evaluating the candidate oils by running a reference test with oil REO-203. This test was successfully completed. The data are summarized in TABLE 8, and a completed test report is included as Appendix A.

C. Method 355 Results

Four of the candidate oils (A1, A2, B, and C) were evaluated in the DDC 6V-53T engine following the Army/CRC 240-Hour Tracked Vehicle Endurance Cycle (Method 355). Prior to each candidate test, the 6V-53T engine was operated for 20 hours using REO-203, following Method 355 procedure to ensure engine build and parts integrity. The tests are discussed in chronological order of running. Summarized test results are presented in TABLE 8.

TABLE 8. Summarized Test Results

Test No.	54	56A	57A	58A	59A
Oil Identification, AL-	19008	19528	19660	19547	20483
Oil Designation	REO-203	B	A1	C	A2
Test Hours	240	151.5	240	21.5	240
Cylinder Eliminated	1L	2R	3R	3L	1R
Liner Distress (5 cyl.)	5.4	38.1	26.5	67.6	6.1
Ring Face Distress (5 cyl.) Nos. 2 and 3 Comp. Rings	4.2	32.8	26.1	45.0	4.0
Piston, WTD (5 cyl.)	253	205	270	152	268
Fe, ppm, at end of test	40	175	34	547	32
Oil Consumption, lb/hr	0.46	0.51	1.02	0.23	0.56
Wear, in. $\times 10^{-4}$					
Liner Bore Diameter Change	5	4	6	8	4
Piston Rings, End Gap Change	4	9	22	46	22

Oil B was evaluated in Test No. 56A. A complete test report is included as Appendix B. Figure 10 shows the plot of used oil iron content versus test hours. At 20 test hours, Cylinders 2R and 3R were replaced because of moderate scuffing. The test was continued from this point, accumulating a total of 50 hours without further incident. It was then decided to continue the test beyond 50 hours to 240 hours or until another cylinder liner required change out. At 151.5 hours, used oil iron content increased substantially, and the test was terminated. Post-test inspection revealed that the following cylinder liners had heavy scuffing: 1R = 100 percent, 2R = 97.5 percent, and 3R = 52 percent. Summarized test results are presented in TABLE 8. With Cylinder 2R eliminated, average five cylinder liner distress was 38.1, and the average ring face distress for Nos. 2 and 3 compression rings was 32.78. The fire land of Piston 2R was distorted and nearing catastrophic failure, and its top compression ring was broken. Compression

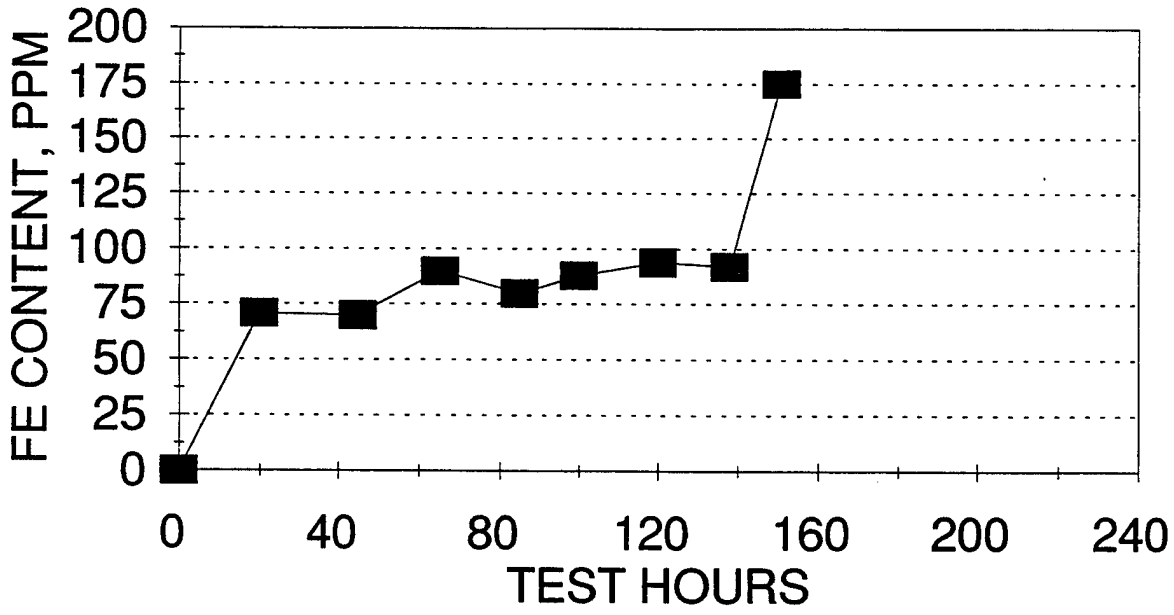

Figure 10. Used oil iron content for Oil B

ring Nos. 2 and 3 from Cylinder 2R were 100 percent collapsed. Summarized ring sticking is shown in TABLE 9. While the overall performance of this oil was not acceptable, the fact that the oil was able to complete 151.5 hours at full output conditions was encouraging and proved to be a substantial improvement over the current arctic engine oil, which must be tested at 21 percent power deration.

TABLE 9. Summarized Ring Sticking

Test No. Oil Designation	56A B	57A A1	58A C	59A A2
Fire Ring	1 – Broken 1 – Partially collapsed (free)	2 – Partially collapsed (free)	2 – Broken 2 – Partially collapsed (free)	1 – Sluggish 2 – Cold stuck (<10%)
No. 2 Compression	1 – Totally collapsed (free)	1 – Partially collapsed (free)	1 – Totally collapsed (free)	1 – Cold stuck (60%)
No. 3 Compression	1 – Totally collapsed (free)	All free	All free	All free

Oil A1 was evaluated in Test No. 57A. A complete test report is included as Appendix C. Figure 11 shows the used oil iron content accumulation with test hours. Oil A1 completed the scheduled 240 hours of Method 355 without a cylinder liner replacement. Post-test engine inspection revealed that two cylinders had 10 percent or less liner distress, and the overall average of five cylinders (without Cylinder 3R) was 26.5 percent. The average ring face distress for the Nos. 2 and 3 compression rings (without Cylinder 3R) was 26.1. (Summarized test results are presented in TABLE 8, and ring sticking results are in TABLE 9.) While both the liner scuffing and ring face distress were higher than desired, the results of this test proved the technical feasibility of formulating an OEA-30 oil that can be evaluated by Method 355 without derating the engine output.

Oil C, which is a commercially available SAE viscosity grade 0W-30 oil, was evaluated in Test No. 58A. A complete test report is included as Appendix D. Figure 12 shows the used oil iron content accumulation with test hours. The test was stopped at 21.5 hours because of very high used oil iron content and increasing engine blowby. Post-test engine inspections revealed severe

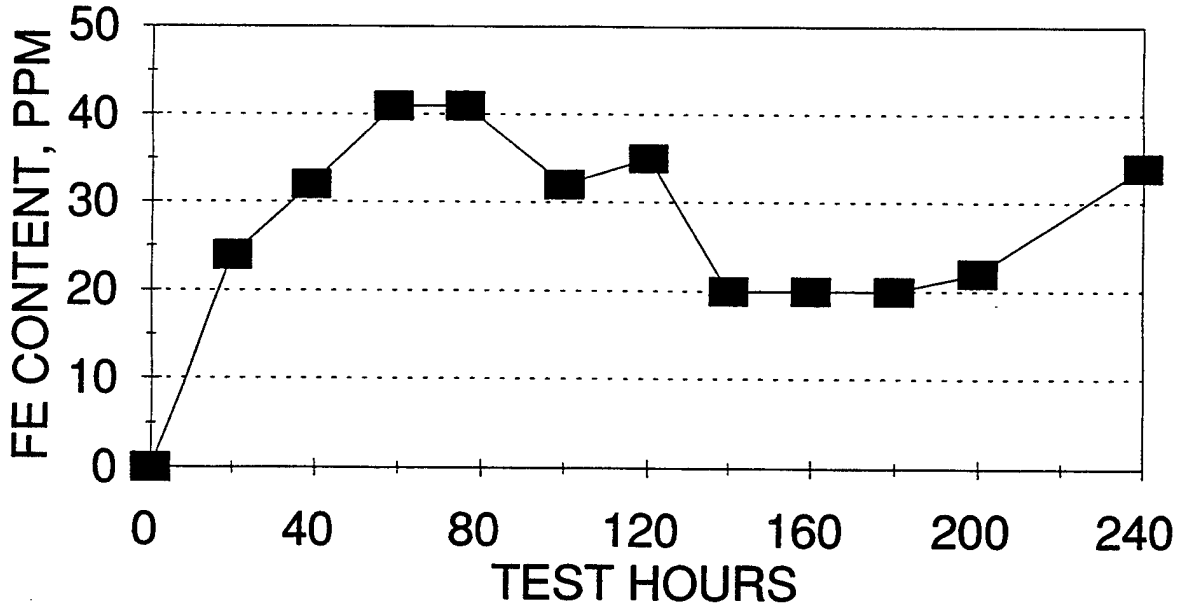

Figure 11. Used oil iron content for Oil A1

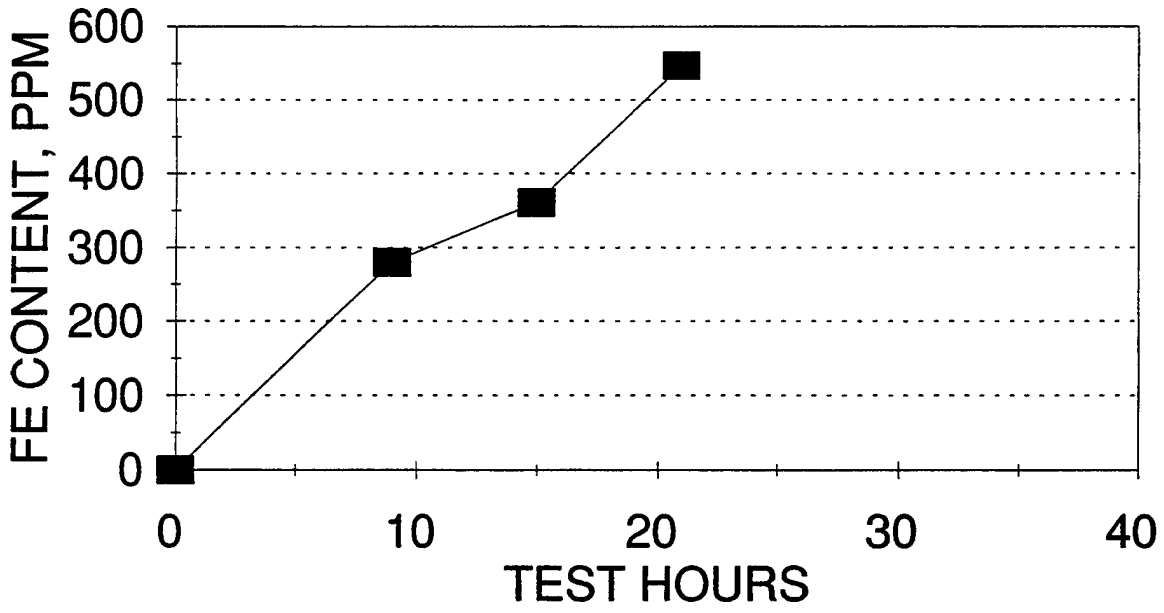

Figure 12. Used oil iron content for Oil C

liner scuffing with four cylinders having between 90 to 100 percent scuffing. Severe ring face distress was also observed. For the second and third compression rings, the ring face distress was 45.03 after eliminating Cylinder 3L. (Summarized test results are presented in TABLE 8.) Two fire rings were broken and three compression rings were collapsed (TABLE 9). This test demonstrated that not all commercially available SAE 0W-30 viscosity grade oils will meet the Army requirements for improved arctic engine oil (i.e., OEA-30).

Oil A2 was evaluated in Test No. 59A. A complete test report is included as Appendix E. Figure 13 shows the used oil iron content accumulation with test hours. Oil A2 completed the scheduled 240 hours of Method 355. Excellent performance was obtained as the five-cylinder average liner distress was only 6.1 percent area coverage, and the Nos. 2 and 3 compression ring demerits were only 4.0. The average weighted piston deposits (WTD) for five cylinders was 268 and the oil consumption was 0.565 lb/hr. (Summarized test data are presented in TABLE 8, and summarized ring sticking data are given in TABLE 9.) This candidate oil proved the technical feasibility of formulating an OEA-30 product that would give acceptable two-cycle diesel engine performance by Method 355 evaluation at full rated power and torque.

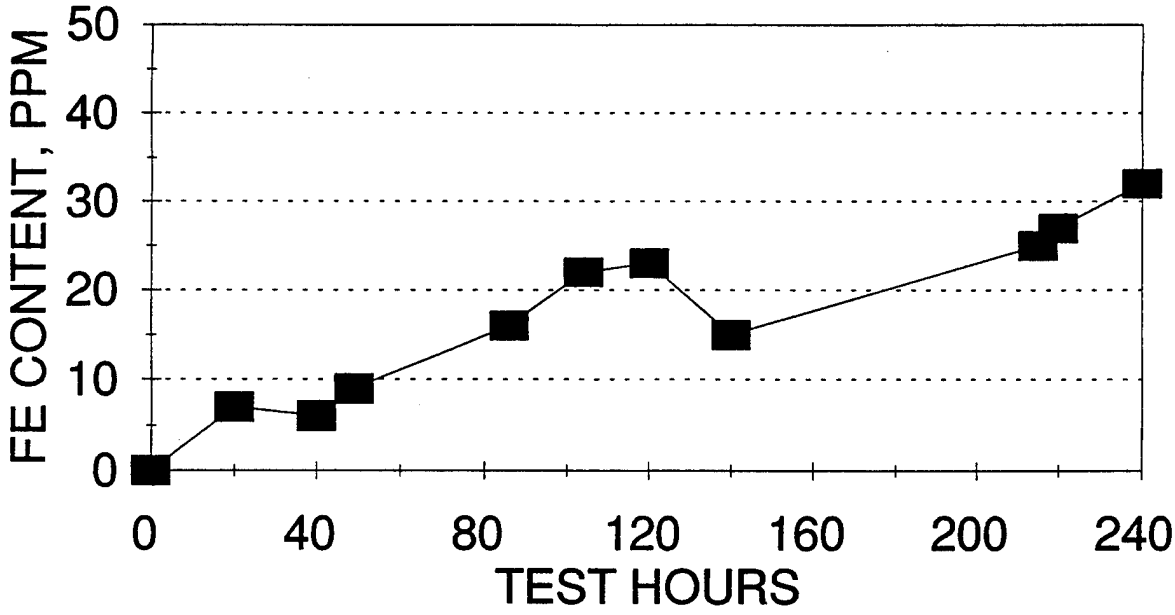

Figure 13. Used oil iron content for Oil A2

A comparison of the performance of the four oils is presented and discussed in this section. Figure 14 shows the end-of-test used oil iron contents, while Fig. 15 shows used oil iron content accumulation rates in ppm per test hour. Oils A1 and A2 were clearly superior with very low end-of-test used oil iron contents. Figure 16 shows the comparative ring face distress values for the Nos. 2 and 3 compression rings, with Oil A2 clearly the best. Ring face distress for the Nos. 2 and 3 compression rings normalized for test hours is shown in Fig. 17, with Oil A2 showing the lowest rate. Comparative cylinder liner distress is shown in Fig. 18, while liner distress normalized for test hours is shown in Fig. 19. Oil A2 had the lowest overall liner distress and distress rate. Finally, comparative average weighted piston deposit ratings are shown in Fig. 20, with Oil C having the lowest WTD. However, when considering test duration, Oils A1, B, and A2 all had similar WTD/hr deposition rates that were lower than the rate for Oil C. This is shown in Fig. 21. By the above measures of performance, candidate Oil A2 was clearly superior.

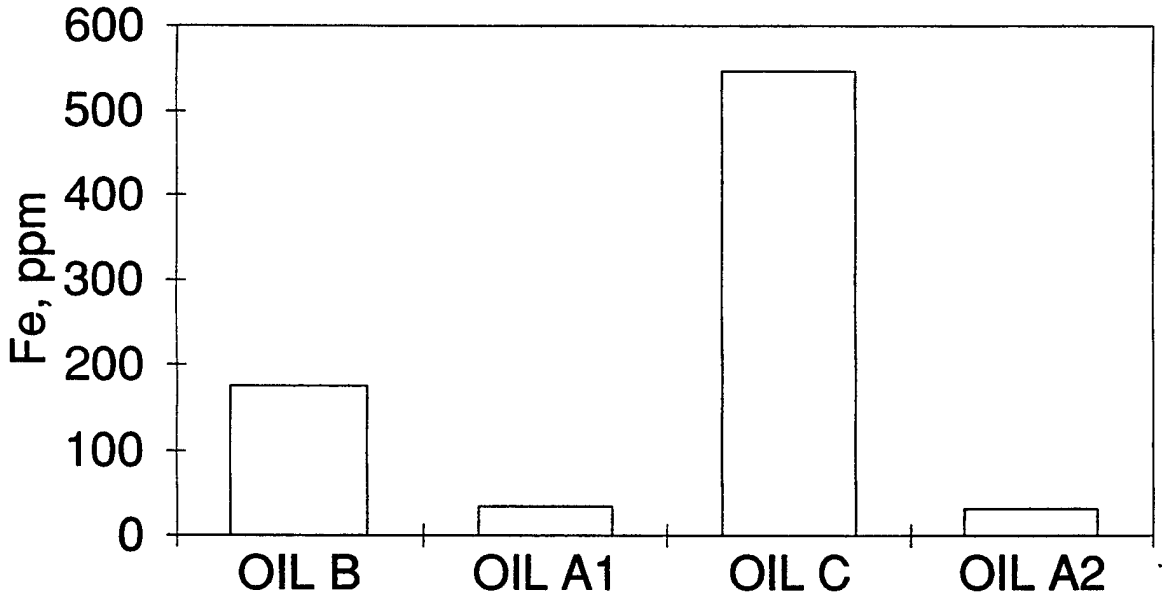

Figure 14. End-of-test used oil iron content

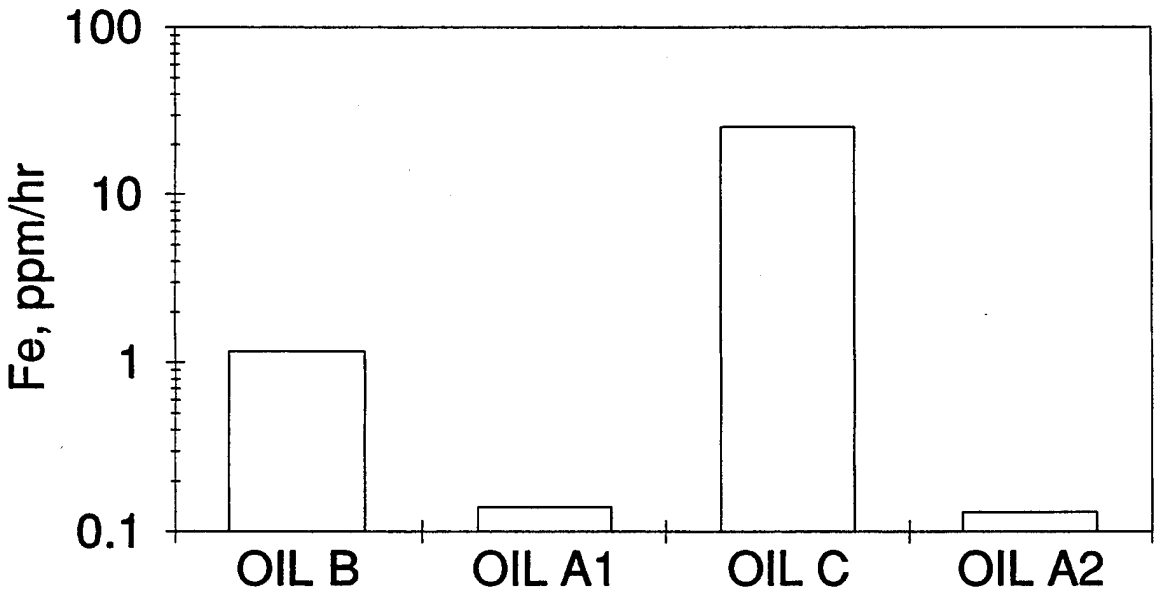

Figure 15. End-of-test normalized used oil iron content

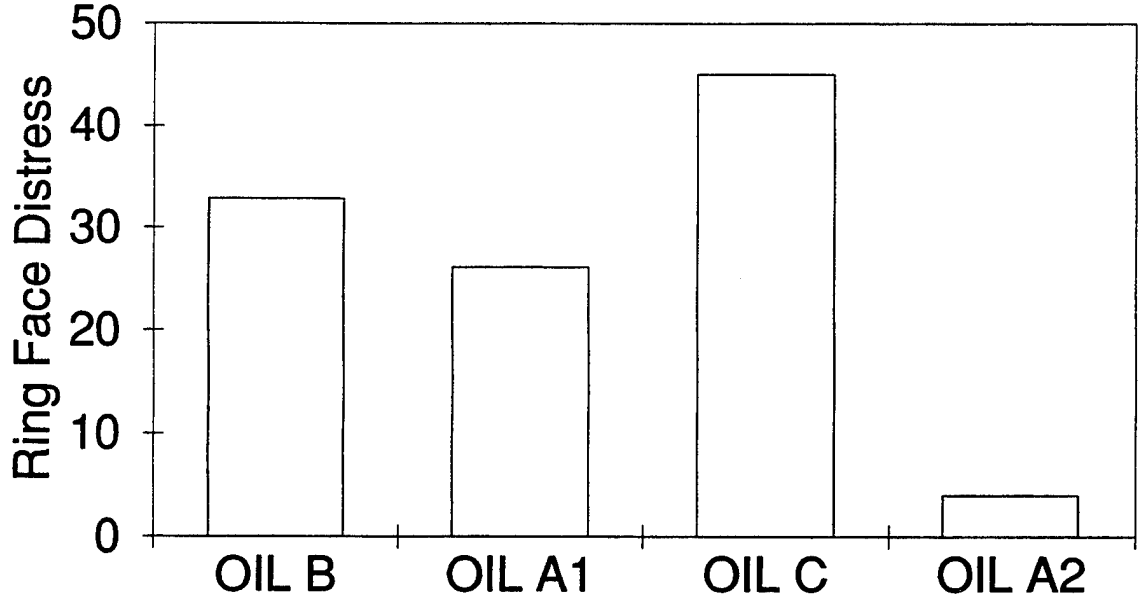

Figure 16. Ring face distress for Nos. 2 and 3 rings

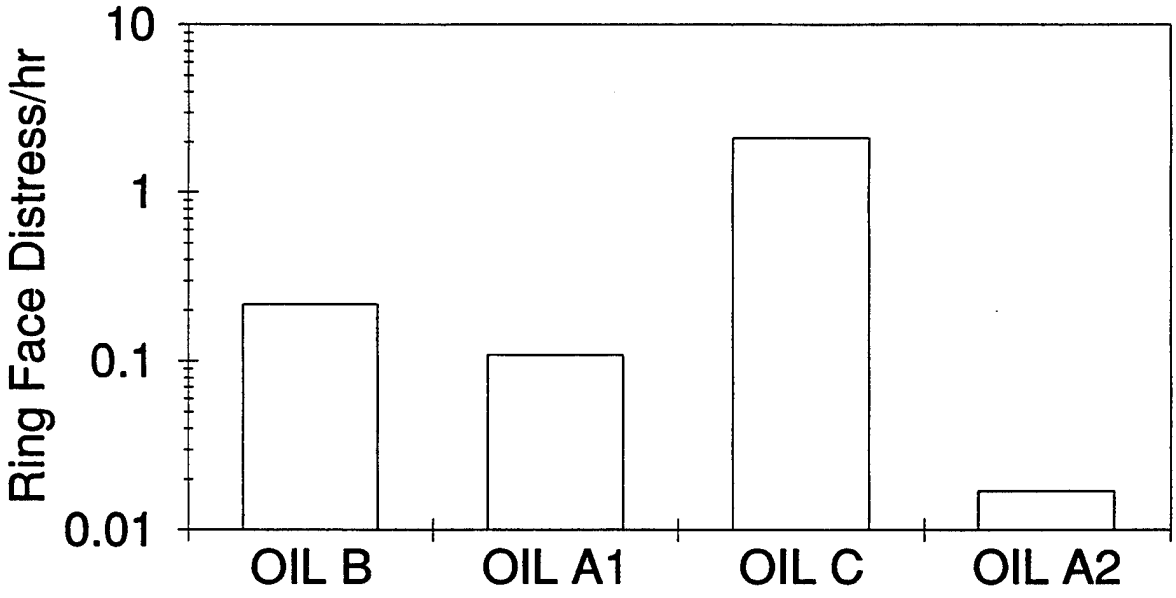

Figure 17. Ring face distress per hour for Nos. 2 and 3 rings

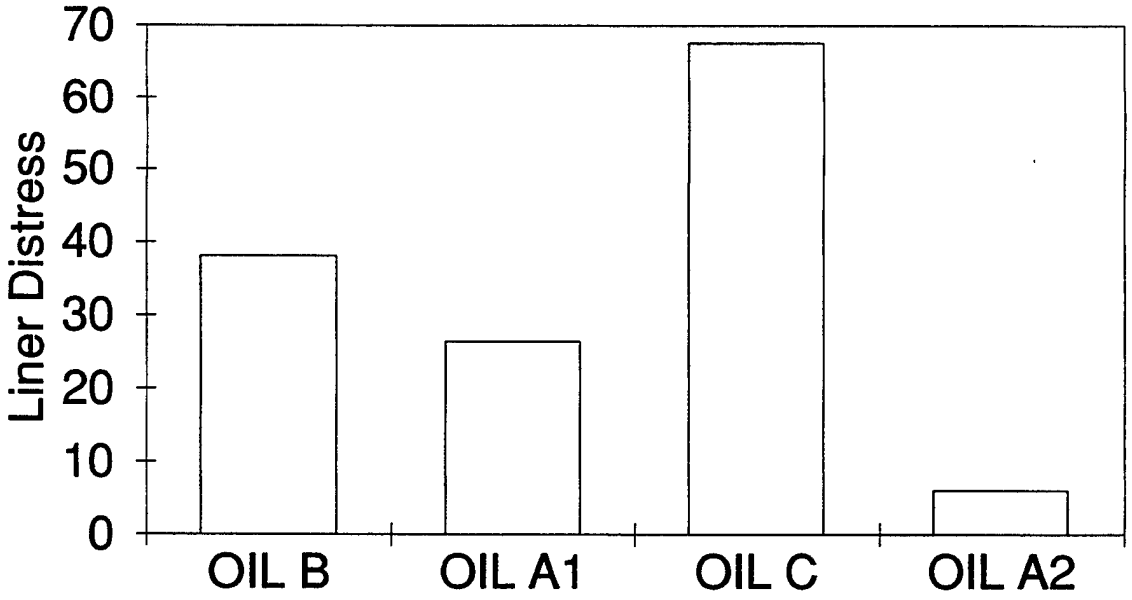

Figure 18. Liner distress

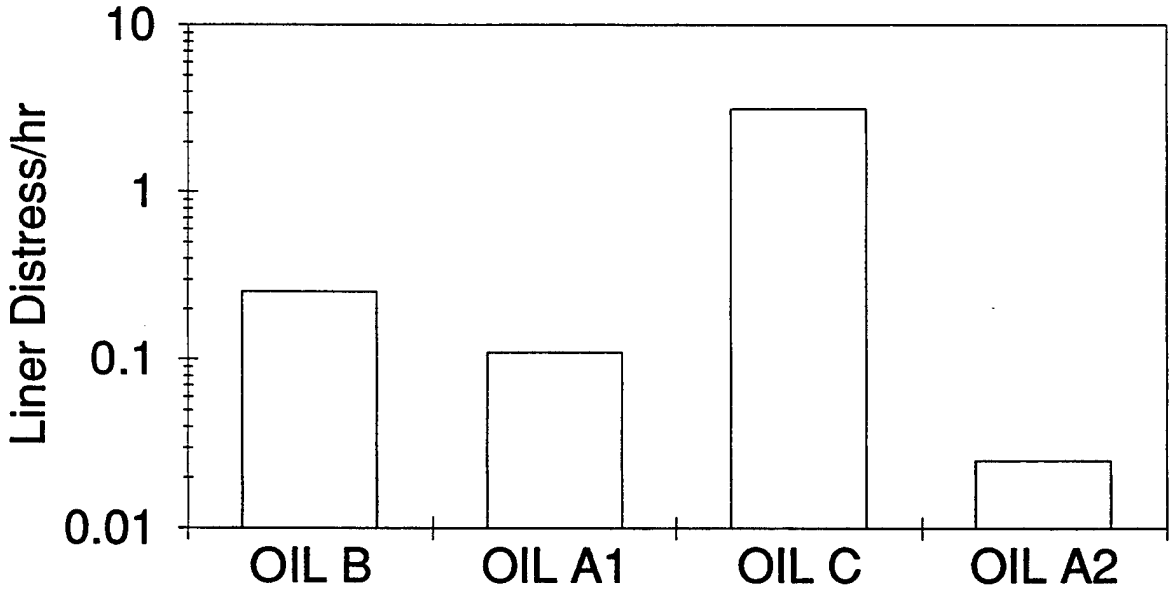

Figure 19. Liner distress per hour

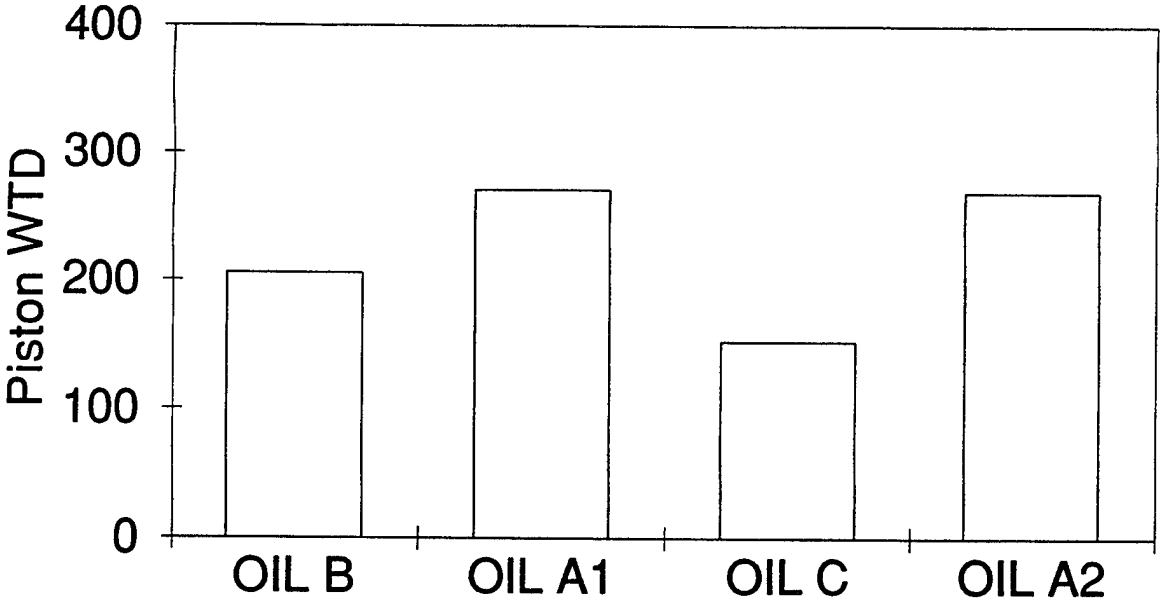

Figure 20. Average WTD for all oils

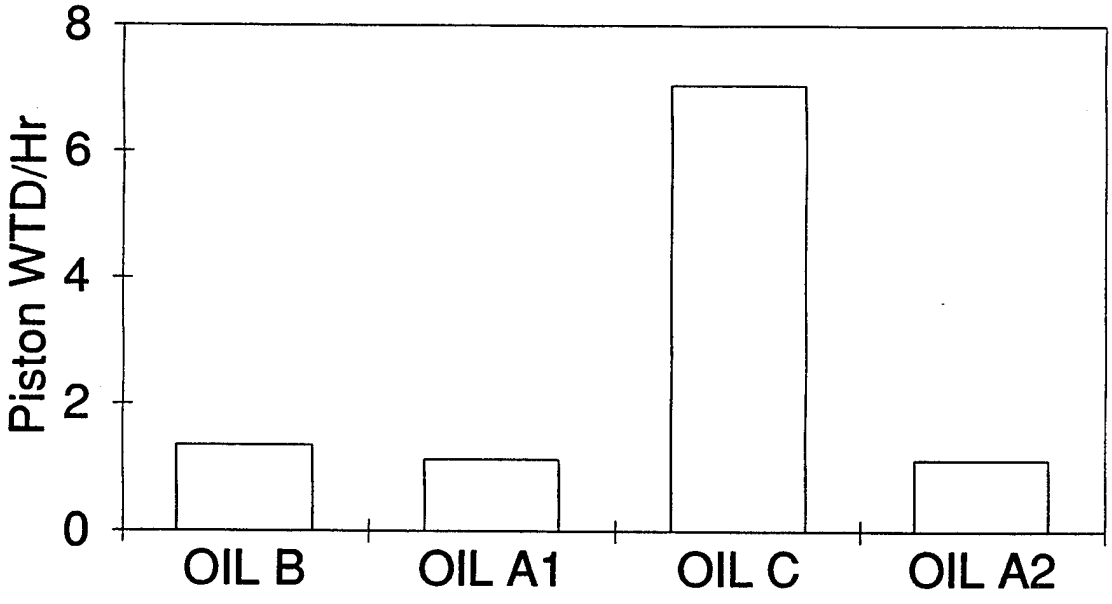

Figure 21. Deposit accumulation WTD per hour

D. Transmission Bench Tests

Currently, engine oils meeting Military Specifications MIL-L-2104F, MIL-L-21260D (13), and MIL-L-46167B are used in the engines, transmissions/final drives, nonhypoid gear boxes, and selected hydraulic systems of Army ground combat/tactical equipment. The rationale for this practice of requiring engine oil to be multifunctional is to reduce logistic supply burden and to reduce the chance of misapplication of transmission-only oil in engines.

Oil B (AL-19528) was evaluated in the following Allison Transmission Division (ATD) C-4 tests:

- Pump wear
- Friction characteristics (graphite)
- Seal compatibility.

These evaluations were conducted as part of another program, and the detailed test reports may be found in Reference 14. The summarized results are presented in TABLE 10. Oil B passed the ATD C-4 Pump Wear Test but failed the C-4 Friction Characteristics (Graphite) Test in the areas of slip time and mid-point friction. It passed all of the seal compatibility tests except for dip cycle (polyacrylate) hardness change.

Oil A1 (AL-19660) was evaluated in the ATD C-4 Seal Compatibility Test; Graphite Clutch Friction Test; Paper Clutch Friction Test; and the Caterpillar TO-4 Friction Properties Test, VC-70, Sequence 1220. Oil A1 passed all of the ATD C-4 Seal Compatibility Tests except for nitrile hardness, as shown in TABLE 11. Oil A1 passed the ATD C-4 Graphite Clutch Friction Test (Appendix F) and the C-4 Paper Clutch Friction Test (Appendix G). The summarized results from these two C-4 friction retention tests are presented in TABLE 12. Finally, in the Caterpillar TO-4 Friction Test, Sequence 1220, which uses a sintered bronze disc, Oil A1 passed all portions except the dynamic coefficient vs. cycle portion. Summarized Sequence 1220 test results are presented in TABLE 13, while the complete test report is included as Appendix H.

TABLE 10. Performance of Oil B in ATD C-4 Tests

Pump Wear

Pattern, %	Scratching	Scoring	Pitting	Burning	Discoloration	Test Result
100	Light	None	None	None	None	Pass

Friction Characteristics (Graphite)

Slip Time, s	Midpoint Friction	Steel Plates Avg. Wear, in.	Clutch Plate Avg. Wear, in.	Pack Clearance, in.	Test Result
(0.76)*	(0.094)	0.003	0.0020	0.020	Fail

Seal Compatibility

Total Immersion		Dip Cycle		Tip Cycle		Fluoroelastomer (Viton)	
Volume Change	Hardness Change	Volume Change	Hardness Change	Volume Change	Hardness Change	Volume Change	Hardness Change
+3.87	+4	+8.32	(–6)	+4.89	–2	+2.66	+1

* Numbers in parentheses indicate a failure

Overall, Oil A1 proved the technical feasibility of using the new OEA-30 oil in powershift transmission applications. Because Oils A1 and A2 have nearly identical additive package chemistry and similar viscosities, the friction test results of Oil A1 should extrapolate to Oil A2. Because of the different basestock compositions of Oils A1 and A2, the seal compatibility results may not extrapolate. No additional transmission bench testing was conducted on this generation of OEA-30 candidates. Additional transmission bench tests will be conducted on OEA-30 candidates having additive systems formulated for the latest heavy-duty diesel engine requirements.

TABLE 11. Performance of Oil A1 in ATD C-4 Seal Compatibility Tests

		Limits
Seal Total Immersion		
Volume %	+1.62	–0.20 to +3.90
Hardness %	(+6)*	–5 to +5
Dip Cycle Seal Test		
Volume %	+7.13	0 to +10
Hardness %	–5	–5 to 0
Tip Cycle Seal Test		
Volume %	+4.08	+1.5 to +6.5
Hardness %	–2	–10 to 0
Viton Total Immersion		
Volume %	+2.16	0 to +4
Hardness %	0	–4 to +4

* Number in parentheses indicates a failure

TABLE 12. Performance of Oil A1 in ATD C-4 Friction Tests

	Slip Time, s	Midpoint Friction	Steel Plates Avg. Wear, in.	Clutch Plate Avg. Wear, in.	Pack Clearance, in.	Test Result
Graphite	0.700	0.106	0.0021	0.0645	0.5080	Pass
Paper						
at <= 5,000 N	0.610	0.079	0.0037	0.0701	1.1684	Pass
at > 5,000 N	0.500	0.104				
at 10,000 N	0.500	0.106				

TABLE 13. Performance of Oil A1 in Caterpillar TO-4 Friction Properties Test, Sequence 1220

Property	Sequence 1220
Dynamic Coefficient vs. Cycle	Fail
Dynamic Coefficient vs. Load	Pass
Dynamic Coefficient vs. Speed	Pass
Energy Limit	Pass
Static Coefficient vs. Cycle	N/A
Static Coefficient vs. Load	Pass
Static Coefficient vs. Speed	Pass
Energy Limit	Pass
Total Wear, in.	0.013
Wear Limit, in.	0.04

E. Oil Reformulation

Based upon the excellent two-cycle diesel engine performance displayed by Oil A2, the U.S. Army requested that the oil supplier reformulate the additive package of the oil to upgrade to API CG-4 performance level. In addition, it was requested that the oil be formulated to have improved low-temperature properties with a kinematic viscosity at –40°C of less than 15,000 cSt. This was accomplished, and the new candidate, Oil A3 (AL-22686), was supplied for evaluation. The inspection properties of Oil A3 are presented in TABLE 14. Candidate Oil A3 is scheduled for further evaluation.

TABLE 14. Inspection Properties of Oil A3

Properties	Oil Identification AL-22686
Kinematic Viscosity, cSt	
–40°C	14,800
40°C	51.58
100°C	10.02
Viscosity Index	185
Apparent Viscosity, cp, CCS at –30°C	3,200
Apparent Viscosity, cp, MRV at –35°C	9,600
High Temp., High Shear Vis., cp, 150°C, D 4624	3.32
Flash Point, °C	232
Pour Point, °C	–51
Sulfated Ash, wt%	0.97
TAN	2.5
TBN, D 4742	7.3
Elements	
S, %, XRF	0.31
ICP, ppm	
Ca	1,647
Mg	571
B	<1
P	1,079
Zn	1,183
Cu	<1

IV. CONCLUSIONS

The following conclusions are made based on the results obtained in this program:

- The technical feasibility of formulating an arctic type, multifunctional diesel engine oil that can withstand full output two-cycle diesel evaluation was proven. Acceptable two-cycle diesel performance was obtained for liner scuffing, ring face distress, piston deposits, and oil consumption with Oil A2.

- A commercially available SAE 0W-30 grade diesel engine oil had unacceptable two-cycle diesel performance.

- Acceptable ATD C-4 bench test performance was achieved with Oil A1 for both graphite and paper clutch friction tests. (Note that Oil A1 and A2 are the same except for a change in basestock ratios and viscosity improver content.)

- Friction properties of sintered bronze with Oil A1 were determined using the Caterpillar TO-4, Sequence 1220 test. Oil A-1 passed seven of eight portions of the test.

- Seal compatibility of Oil A1, determined using the ATD C-4 tests, was acceptable for polyacrylate, silicone, and viton elastomers. Nitrile elastomer was a borderline fail for hardness.

- Oil A-2 was reformulated to have expected API CG-4 performance.

V. RECOMMENDATIONS

The following recommendations are offered:

- The reformulated OEA-30 candidate oil should be evaluated in the tests required by API CG-4 to confirm performance.

- The reformulated OEA-30 candidate oil should be evaluated in the ATD C-4 and Caterpillar TO-4 transmission oil bench tests required by MIL-L-2104F.

- Low temperature oil pumpability of OEA-30 candidates should be characterized in a diesel engine and compared with the performance of the current OEA oil.

- Pilot field demonstrations should be conducted once API CG-4 and MIL-L-2104F transmission requirements have been confirmed. The field demonstrations should include both high ambient temperature and very low ambient temperature conditions.

VI. LIST OF REFERENCES

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APPENDIX A

Test 6V-53T — 54

REO-203
AL-19008-L
Reference Run

6V-53T
TEST 54
DISCUSSION

Test 54, utilizing FTM 355, was performed as a reference test utilizing Reference Engine Oil (REO) 203 as the lubricant. During the course of the test, frequent adjustments were made to the rack position to recover power loss at 2800 rpm. An investigation into the cause for the frequent adjustments was made after completion of the test. The need for the excessive adjustments was determined to be caused by engine vibration and excessive rack actuator force, which was causing the rack lever to slip on the unkeyed rack shaft. This slippage had the effect of limiting the rack travel at the injectors. After adjusting the actuator force and travel, full-power was recovered at end of test.

Test 54 was completed without changing out a cylinder kit and had acceptable performance: average liner distress (of five cylinders) was 5.4 and average Nos. 2 and 3 compression ring distress (of five cylinders) was 10.00 (4.23 demerits).

6V-53T
TEST 54
ENGINE REBUILD MEASUREMENTS
Model Number: 5063-5395
AL-19008-L

	Minimum,		Maximum,		Average,		Specified Limits*
	inches	mm	inches	mm	inches	mm	
CYLINDER BLOCK BORE							
Inside Diameter (Bottom)	4.3566	110.653	4.3575	110.676	4.3571	110.667	4.3565 (110.655) - 4.3575 (110.681) New - 4.3595 (110.731) Max
Out-of-Round	0.0000	0.000	0.0021	0.053	0.0005	0.013	- 0.0015 (0.038) Max
Taper	0.0000	0.000	0.0012	0.030	0.0003	0.008	- 0.0015 (0.038) Max
CYLINDER LINERS (Installed)							
Inside Diameter	3.8754	98.431	3.8765	98.459	3.8760	98.447	3.8752 (98.430) - 3.8767 (98.468)
Out-of-Round	0.0000	0.000	0.0006	0.015	0.0002	0.006	- 0.0015 (0.038) Max
Taper	0.0001	0.003	0.0008	0.020	0.0004	0.010	- 0.0015 (0.038) Max
Piston Diameter (at Skirt)	3.8679	98.241	3.8689	98.266	3.8684	98.253	3.8669 (98.219) - 3.8691 (98.775)
Piston Skirt to Cylinder Liner Clearance	0.0069	0.175	0.0083	0.211	0.0077	0.195	0.0061 (0.155) - 0.0098 (0.249)
COMPRESSION RINGS							
Gap (No. 1, Fire ring)	0.026	0.66	0.030	0.76	0.027	0.70	0.020 (0.51) - 0.040 (1.0)
Gap (Nos. 2, 3, 4)	0.024	0.61	0.028	0.71	0.026	0.67	0.020 (0.51) - 0.040 (1.0)
RING-TO-GROOVE CLEARANCE							
Top (No. 1, Fire Ring)	0.0035	0.089	0.0045	0.114	0.0038	0.097	0.0030 (0.08) - 0.0066 (0.17)
No. 2, Compression Ring	0.0075	0.190	0.0085	0.216	0.0080	0.203	0.007 (0.18) - 0.0105 (0.27)
No. 3 & 4, Compression Rings	0.0050	0.127	0.0075	0.190	0.0063	0.160	
OIL CONTROL RINGS (Nos. 5,6,7)							
Gap	0.0090	0.229	0.0135	0.343	0.0110	0.280	0.010 (0.25) - 0.020 (0.51)
Ring-to-Groove Clearance	0.0015	0.038	0.0030	0.076	0.0023	0.059	0.0015 (0.038) - 0.0055 (0.140)
PISTON PIN							
Pin-to-Piston Bushing Clearance	0.0029	0.074	0.0031	0.079	0.0029	0.075	0.0025 (0.064) - 0.0034 (0.86)
Pin-to-Connecting Rod Bushing Clearance	0.0016	0.041	0.0018	0.046	0.0017	0.043	0.0010 (0.025) - 0.0019 (0.048)
Connecting Rod Bearing-to-Journal Clearance	0.0018	0.046	0.0027	0.069	0.0022	0.057	0.0011 (0.028) - 0.0041 (0.104)
Main Bearing-to-Journal Clearance	0.0041	0.104	0.0046	0.117	0.0045	0.113	0.0030 (0.076) - 0.0050 (0.127)
Camshaft Bearing-to-Journal Clearance	0.0048	0.122	0.0054	0.137	0.0050	0.128	0.0045 (0.114) - 0.0060 (0.152)

* Measurements are in inches and (mm).

6V-53T
TEST 54
SUPPLEMENTAL ENGINE BUILDUP DATA

Cylinder No.	Upper Oil Control Ring Tension, lbs	Liner Accoustic Velocity, in/sec	Liner Surface Roughness, μ in.
1L	21.06	173580	46
2L	21.12	172055	42
3L	21.13	170790	44
1R	19.42	171390	42
2R	21.58	165905	46
3R	21.47	169795	43
Average	20.96	170586	44

6V-53T
240-HOUR TRACKED VEHICLE CYCLE ENDURANCE TEST
TEST 54
OPERATING CONDITIONS SUMMARY

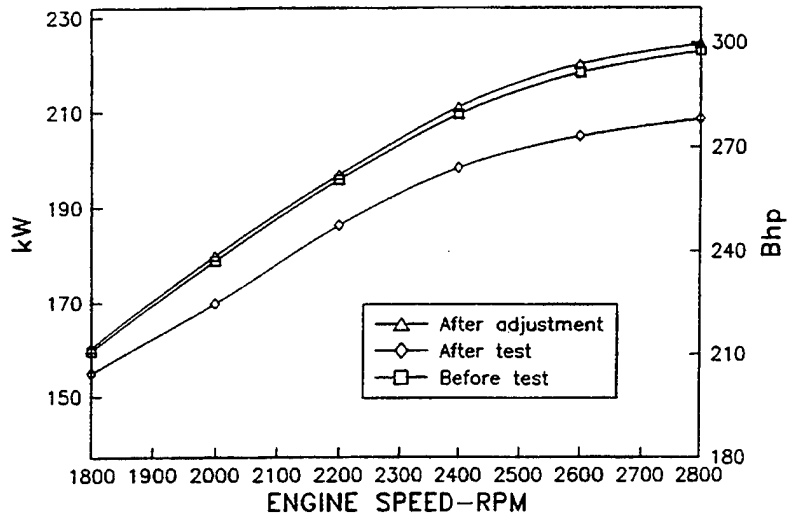
Lubricant: AL-19008-L Fuel: Caterpillar 1H2/1G2

	Maximum Power Mode (2800 RPM)		Maximum Torque Mode (2200 RPM)	
	Mean	*Standard Deviation	Mean	*Standard Deviation
Engine Speed, rpm	2799	3	2199	2
Torque, lb-ft (N-m)	553 (749)	13 (18)	613 (832)	26 (35)
Fuel Consumption, lb/hr (kg/hr)	114.3 (51.87)	2.679 (1.217)	98.25 (44.57)	4.482 (2.033)
Observed Power, bhp (kW)	295 (220)	7 (5)	257 (191)	11 (8)
BSFC, lb/bhp-hr (g/kW-hr)	0.388 (0.236)	0.002 (0.001)	0.383 (0.233)	0.004 (0.002)
Temperatures, °F (°C)				
Exhaust before Turbo	930 (499)	42 (23)	944 (507)	74 (41)
Exhaust after Turbo	770 (410)	35 (19)	809 (432)	30 (17)
Water Jacket Inlet	164 (73)	3 (2)	163 (73)	3 (2)
Water Jacket Outlet	173 (78)	3 (2)	173 (78)	3 (2)
Oil Sump	236 (113)	7 (4)	227 (108)	8 (4)
Fuel at Filter	97 (36)	5 (3)	96 (36)	5 (3)
Inlet Air	91 (33)	4 (2)	91 (33)	4 (2)
Airbox	264 (129)	4 (2)	220 (104)	5 (3)
Pressures				
Exhaust before Turbo, psi (kPa)	14.2 (97.8)	0.7 (4.7)	9.6 (65.9)	0.5 (3.5)
Exhaust after Turbo, in. Hg (kPa)	1.58 (5.4)	0.27 (0.9)	0.96 (3.3)	0.15 (0.5)
Compressor Discharge, psi (kPa)	14.6 (100.9)	0.7 (4.8)	10.6 (73.2)	0.6 (4.4)
Blower Discharge, psi (kPa)	17.7 (121.8)	0.9 (6.0)	10.8 (74.4)	0.6 (4.1)
Oil Gallery, psi (kPa)	43.8 (301.7)	1.6 (11.1)	40.8 (281.2)	2.3 (15.9)
Intake Vacuum, in. H_2O (kPa)	9.410 (2.342)	1.669 (0.415)	5.791 (1.441)	1.805 (0.449)
Ambient Conditions				
Dry Bulb Temperature, °F (°C)	83.5 (28.6)	6.5 (3.6)	83.5 (28.6)	6.1 (3.4)
Wet Bulb Temperature, °F (°C)	69.3 (20.7)	7.4 (4.1)	69.5 (20.8)	7.5 (4.2)
Barometric Pressure, in. Hg (kPa)	29.09 (98.53)	0.12 (0.39)	29.10 (98.55)	0.12 (0.41)

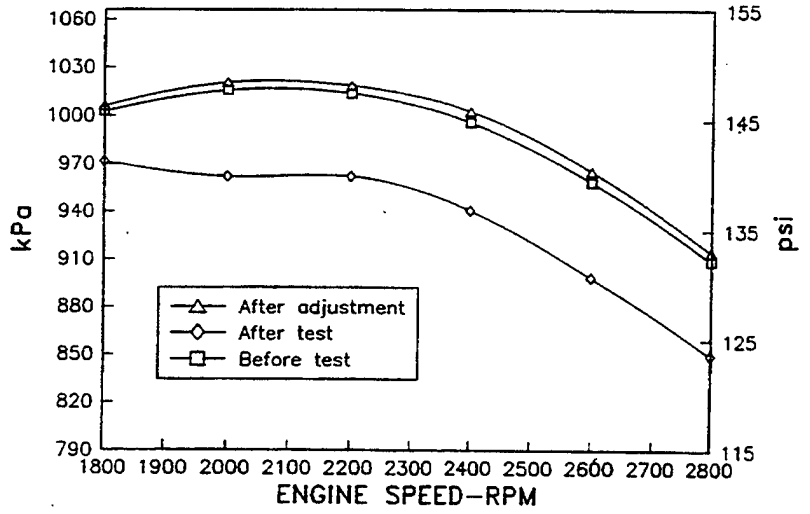
* 68% of the values for a given variable occur within ±1 standard deviation of the mean; 95% occur within ±2 standard deviations.

6V-53T 240-HOUR TRACKED VEHICLE CYCLE BEFORE AND AFTER TEST 54 PERFORMANCE DATA

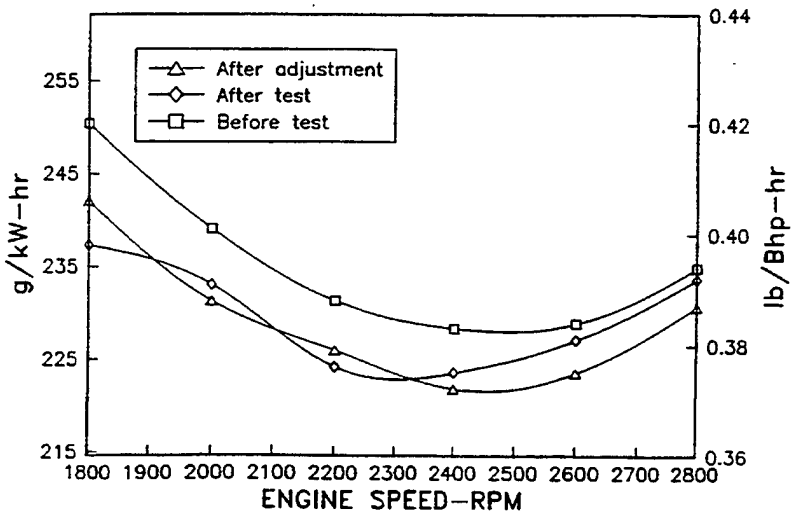
POWER



BMEP



BSFC



6V-53T
TEST 54
LUBRICANT ANALYSIS
Lubricant: AL-19008-L

	ASTM Test Method	Test Time, Hours												
		0	20	40	60	80	100	120	140	160	180	200	220	240
Kinematic Viscosity at 40°C (104°F), cSt	D 445	104.08	--	--	--	107.30	--	110.00	--	--	108.50	--	--	112.30
Kinematic Viscosity at 100° (212°F), cSt	D 445	11.82	--	--	--	12.07	--	12.28	--	--	12.22	--	--	12.71
Total Acid Number, mg KOH/g	D 664	3.11	--	--	--	1.79	--	3.32	--	--	2.62	--	--	2.44
Total Base Number, mg KOH/g	D 664	4.39	--	--	--	3.61	--	3.45	--	--	2.87	--	--	3.12
Pentane B Insolubles, wt%	D 893	0.01	--	--	--	0.13	--	0.20	--	--	0.17	--	--	0.28
Toluene B Insolubles, wt%	D 893	<0.01	--	--	--	0.12	--	0.18	--	--	0.15	--	--	0.26
Flash Point, °C/°F	D 92	243/470	--	--	--	--	--	--	--	--	--	--	--	252/486

6V-53T
TEST 54
TOTAL OIL CONSUMPTION AND WEAR METALS BY XRF

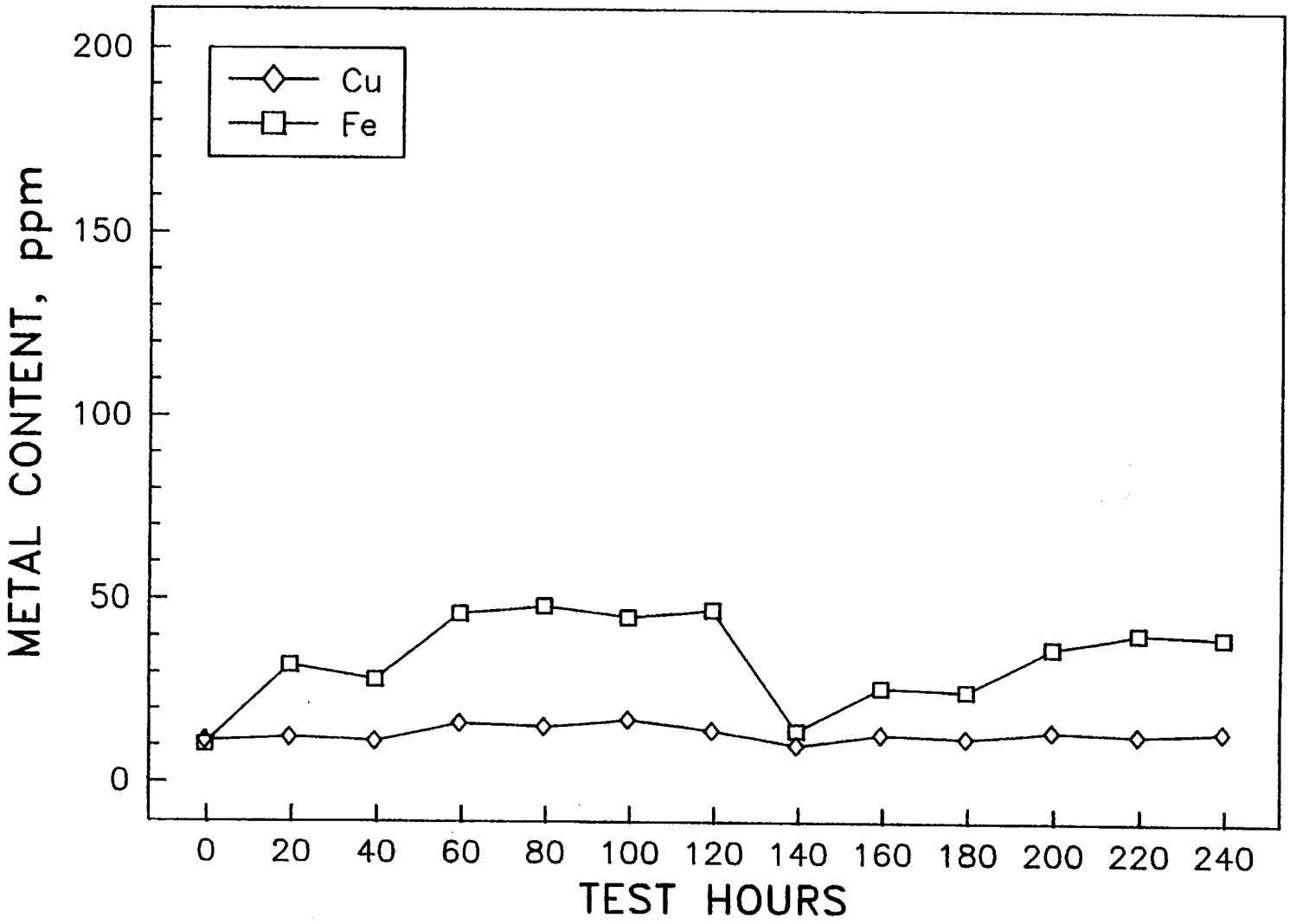
Lubricant: AL-19008-L

Test Time, Hours	Total Oil Consumed, lb (kg)	Wear Metals, ppm	
		Fe	Cu
0		<10	11
20	20.41 (9.26)	32	12
40	31.66 (14.36)	28	11
60	41.08 (18.63)	46	16
80	50.39 (22.86)	48	15
100	59.33 (26.91)	45	17
120	Oil Change	47	14
140	61.91 (28.08)	14	<10
160	74.01 (33.57)	26	13
180	82.53 (37.44)	25	12
200	89.70 (40.69)	37	14
220	100.70 (45.68)	41	13
240	--	40	14

Average oil consumption rate: 0.46 lb/hr (0.21 kg/hr).

WEAR METAL CONCENTRATION IN USED OIL

6V-53T TEST NO. 54 AL-19008-L



6V-53T
TEST 54
Lubricant: AL-19008-L
Cylinder Liner Wear Measurements

Cylinder Liner Bore Diameter Changes*

Cylinder Number

	1L				2L				3L			
	T-AT		F-B		T-AT		F-B		T-AT		F-B	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
Top	0.0026	0.066	-0.0003	-0.008	0.0006	0.015	-0.0003	-0.008	0.0001	0.003	-0.0002	-0.005
Middle	0.0005	0.013	0.0003	0.008	0.0005	0.013	0.0003	0.008	0.0005	0.013	0.0004	0.010
Bottom	0.0005	0.013	0.0006	0.015	0.0004	0.010	0.0004	0.010	0.0006	0.015	0.0006	0.015

Cylinder Number

	1R				2R				3R			
	T-AT		F-B		T-AT		F-B		T-AT		F-B	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
Top	0.0009	0.023	0.0001	0.003	0.0007	0.018	0.0000	0.000	0.0007	0.018	-0.0001	-0.003
Middle	0.0006	0.015	0.0004	0.010	0.0006	0.015	0.0003	0.008	0.0005	0.013	0.0002	0.005
Bottom	0.0008	0.020	0.0001	0.003	0.0003	0.008	0.0011	0.028	0.0004	0.010	0.0002	0.005

Average Change

	T-AT		F-B	
	in.	mm	in.	mm
Top	0.0009	0.024	-0.0001	-0.003
Middle	0.0005	0.014	0.0003	0.008
Bottom	0.0005	0.013	0.0005	0.013

* T-AT = Thrust-Antithrust; F-B = Front-Back Direction.

6V-53T
TEST 54
Lubricant: AL-19008-L
Piston Ring Wear Measurements

Piston Ring End Gap Change

Ring No.	1L		2L		3L		1R		2R		3R		Average Change	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
1	0.0040	0.102	0.0030	0.076	0.0020	0.051	0.0030	0.076	0.0035	0.089	0.0020	0.051	0.0029	0.074
2	0.0020	0.051	0.0010	0.025	0.0010	0.025	0.0010	0.025	0.0020	0.051	0.0020	0.051	0.0015	0.038
3	0.0010	0.025	0.0010	0.025	0.0010	0.025	0.0005	0.013	0.0015	0.038	0.0010	0.025	0.0010	0.025
4	0.0030	0.076	0.0020	0.051	0.0005	0.013	0.0015	0.038	0.0005	0.013	0.0010	0.025	0.0014	0.036
5	0.0075	0.190	0.0070	0.178	0.0070	0.178	0.0080	0.203	0.0060	0.152	0.0070	0.178	0.0071	0.180
6	0.0090	0.229	0.0070	0.178	0.0060	0.152	0.0080	0.203	0.0080	0.203	0.0070	0.178	0.0075	0.190
7	0.0090	0.229	0.0070	0.178	0.0069	0.175	0.0060	0.152	0.0080	0.203	0.0070	0.178	0.0073	0.186

Overall average change: 0.0041 in. (0.104 mm)

Average Piston Ring Radial Width Change

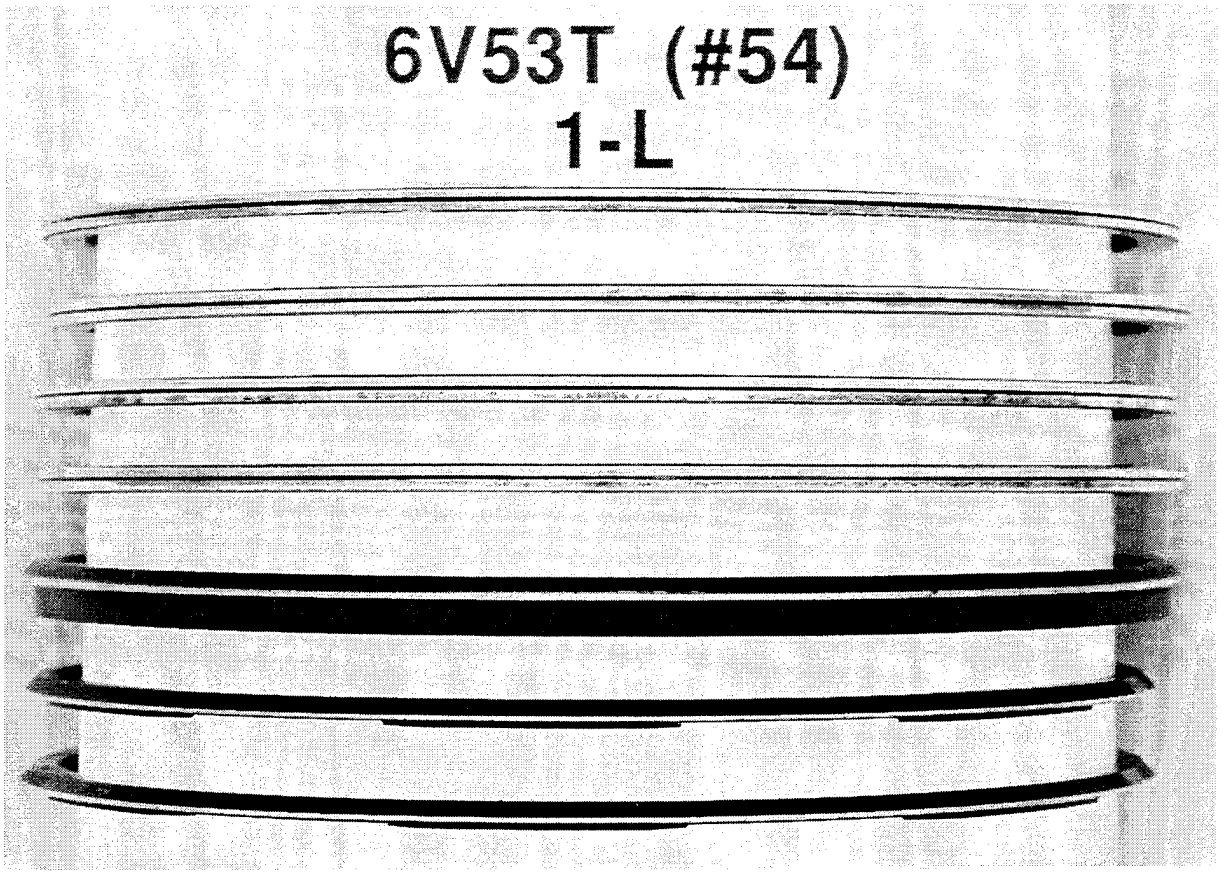
Ring No.	1L		2L		3L		1R		2R		3R		Average Change	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
1	0.0001	0.002	-0.0002	-0.004	-0.0003	-0.009	-0.0004	-0.011	-0.0004	-0.010	-0.0007	-0.017	-0.0003	-0.008
2	0.0003	0.007	0.0004	0.009	0.0008	0.020	0.0006	0.014	0.0005	0.013	0.0007	0.017	0.0005	0.013
3	0.0008	0.020	0.0006	0.015	0.0006	0.015	0.0005	0.012	0.0005	0.014	0.0005	0.012	0.0006	0.015
4	0.0004	0.010	0.0009	0.022	0.0006	0.014	0.0009	0.024	0.0006	0.016	0.0006	0.015	0.0007	0.017

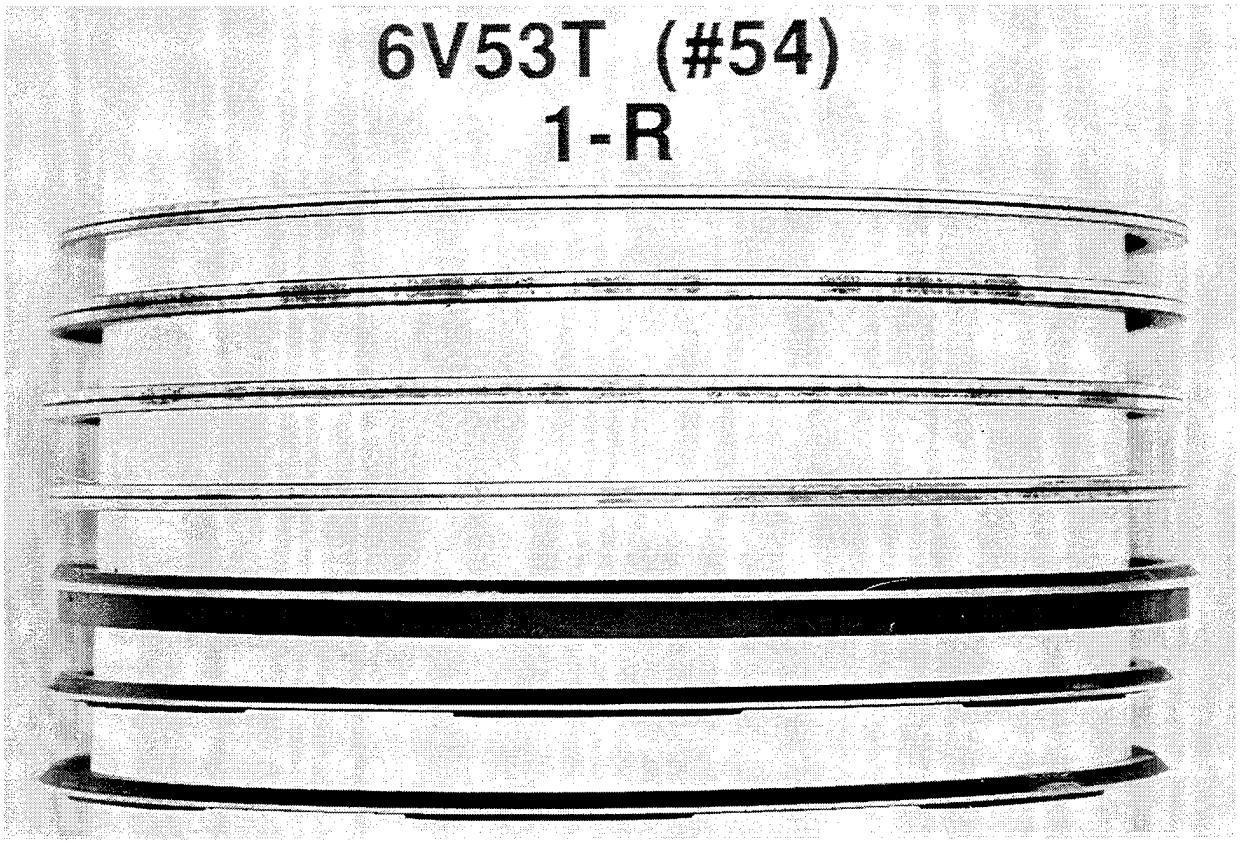
Overall average change: 0.0004 in. (0.009 mm)

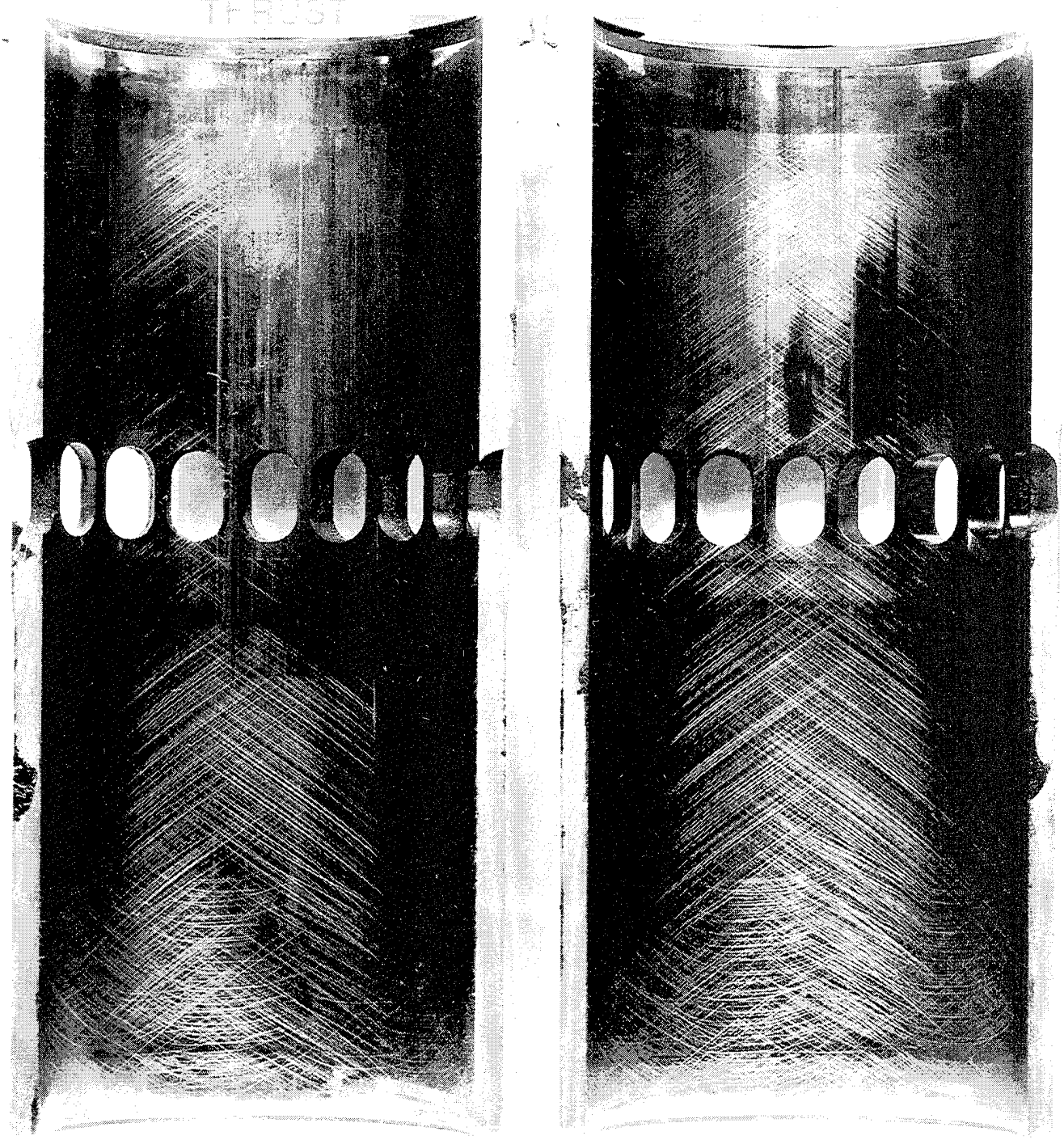
6V-53T
TEST 54
Lubricant: AL-19008-L
Post-Test Engine Conditions and Deposits

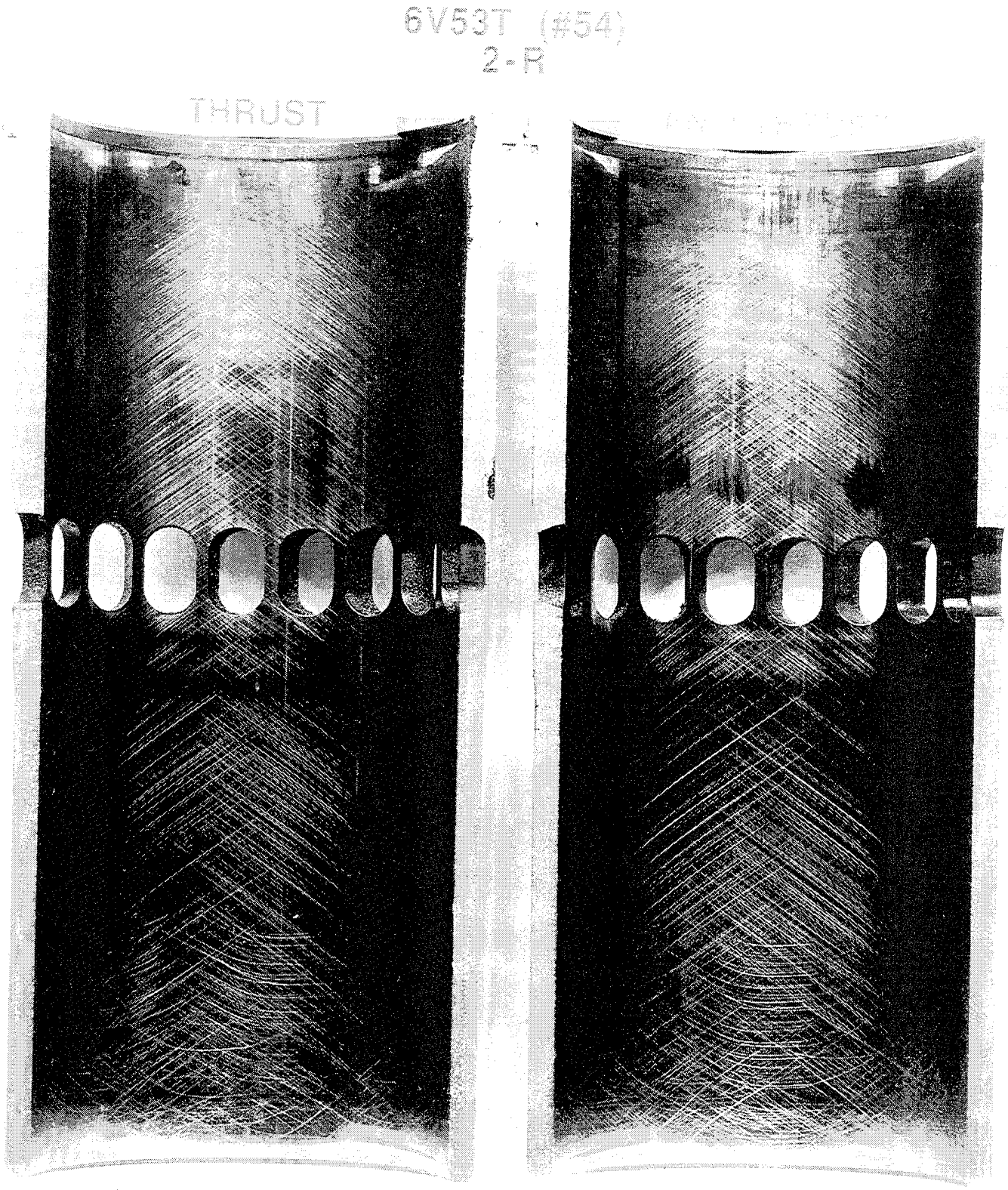
	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
A) Cylinder Liner							
Intake Port Plugging, % Restriction	4	4	4	4	4	4	4.00
Liner Scuffing, % Area							
Thrust	43	1	1	32	4	0	13.50
Anti-Thrust	1	0	1	4	2	4	2.00
% Avg Area	22	0.5	1	18	3	2	7.75
						Overall:	7.75
% Area Bore Polished							
Thrust	19	23	28	28	30	16	24.00
Anti-Thrust	13	29	12	36	26	19	22.50
% Avg Area	16	26	20	32	28	17.5	23.25
						Overall:	23.25
% Area Liner Distress							
Thrust	53	1	1	37	4	0	16.00
Anti-Thrust	1	0	1	4	2	4	2.00
% Avg Area	27	0.5	1	20.5	3	2	9.00
						Overall:	9.00
B) Rings							
Ring Face Distress, (Demerits)							
No. 1	18.75	2.50	4.25	14.75	8.00	4.00	8.71
No. 2	9.50	1.75	2.50	12.75	3.50	1.50	5.25
No. 3	10.50	1.75	1.00	13.25	3.50	0.75	5.13
No. 4	11.50	2.00	1.25	13.25	4.50	0.75	5.54
						Overall:	6.16
C) Pistons							
Piston Skirt Rating*							
Thrust	Lt.S	Lt.S	Lt.S	Lt.S-3%SC	Lt.S-1%SC	Lt.S	
Anti-Thrust	Lt.S-2%SC	Lt.S	Lt.S	Lt.S	Lt.S	Lt.S	
Piston WTD Rating**	199.51	256.50	231.86	273.87	254.87	245.87	243.75
Ring Sticking***							
No. 1	F	F	F	F	F	F	
No. 2	F	F	F	F	F	F	
No. 3	F	F	F	F	F	F	
No. 4	F	F	F	F	F	F	
D) Exhaust Valves							
Deposits							
Head+	55 LtC 45 MC	55 LtC 50 MC	45 LtC 55 MC	70 LtC 30 MC	40 LtC 60 MC	70 LtC 30 MC	
Face	----------Light amount of Carbon and Ash Embedment----------						
Tulip++	1.0	1.0	1.0	1.0	1.0	1.0	
Stem	----------All Stems 5% to 15% #9 Lacquer----------						
Surface Conditions							
Freeness in Guide	----------Free----------						
Head	----------Normal----------						
Face	----------Normal----------						
Seat	----------Normal----------						
Stem	----------Normal----------						
Tip	----------Normal----------						

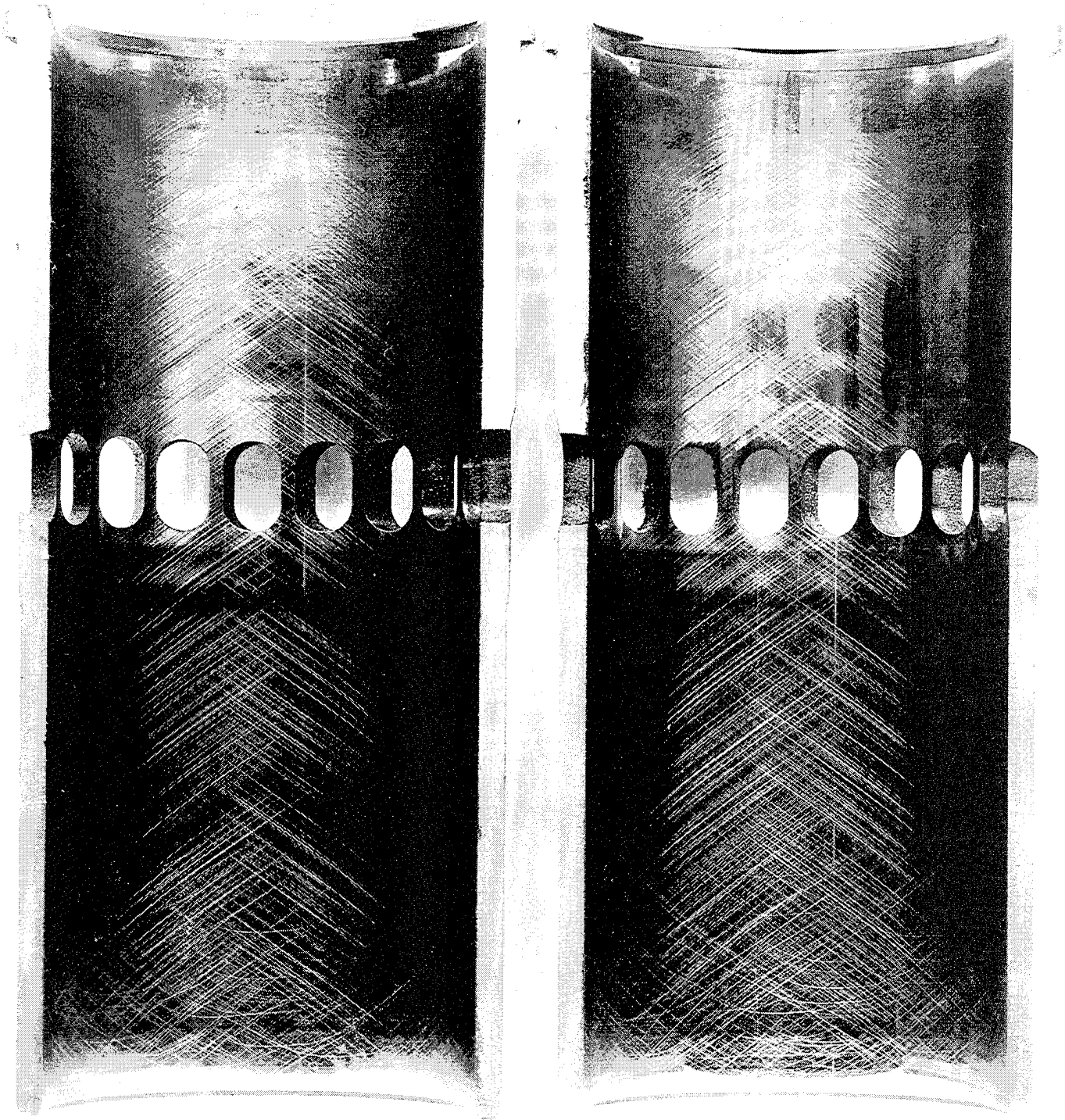
* Lt. = Light, S = Scratches, PM = Plating Melted, N = Normal, SC = Scuffing, B = Burn.
** CRC Weighted Total Deposits (0 = Least, 900 = Most).
*** HS = Hot Stuck, CS = Cold Stuck, P = Pinched, F = Free, N = Normal, C = Chipped.
\+ LtC = Light Carbon, MC = Medium Carbon, the number indicates percentage.
++ The higher the number, the darker the lacquer (0 = Lightest, 9 = Darkest).

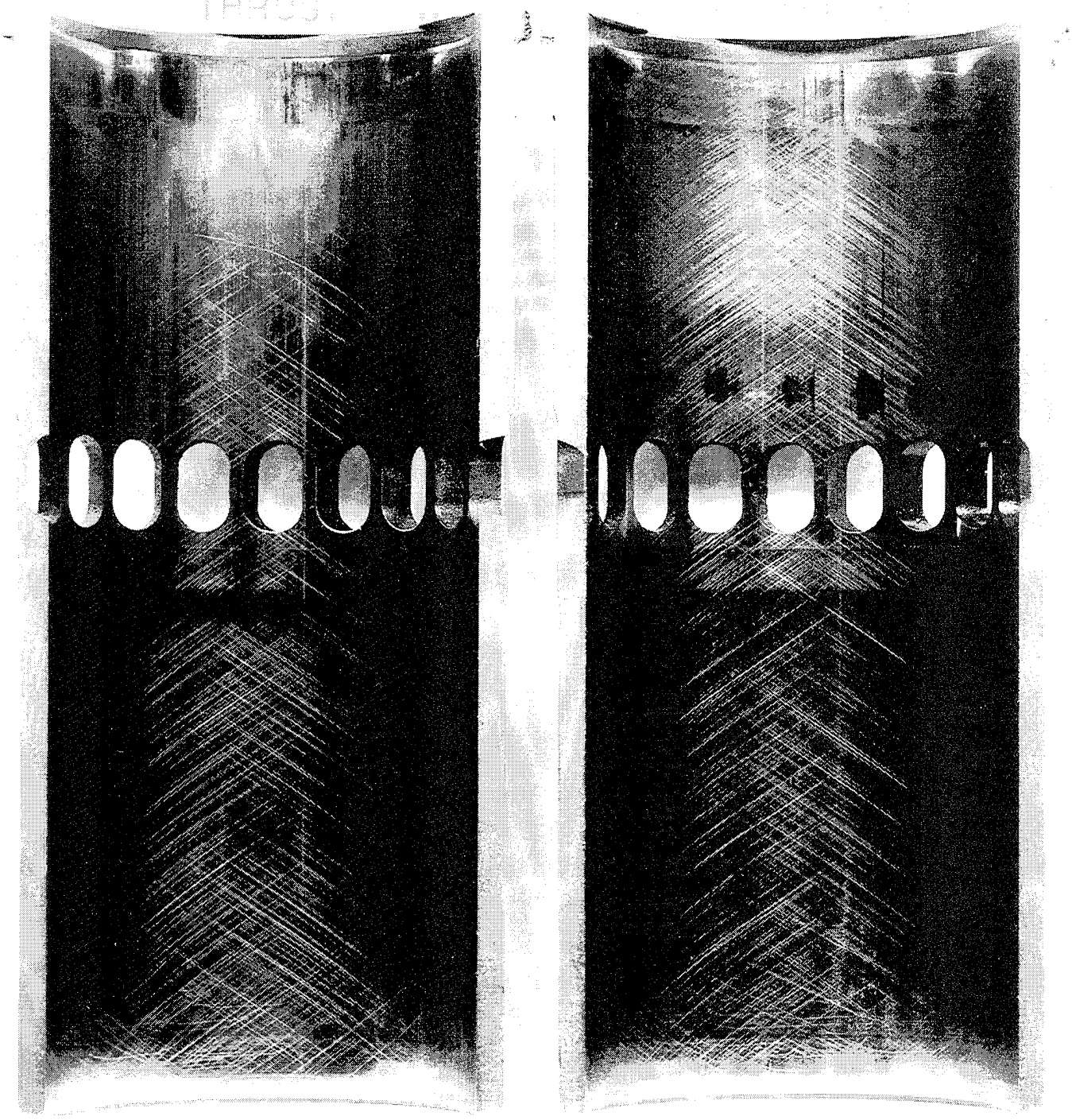

6V53T (#54)
1-L

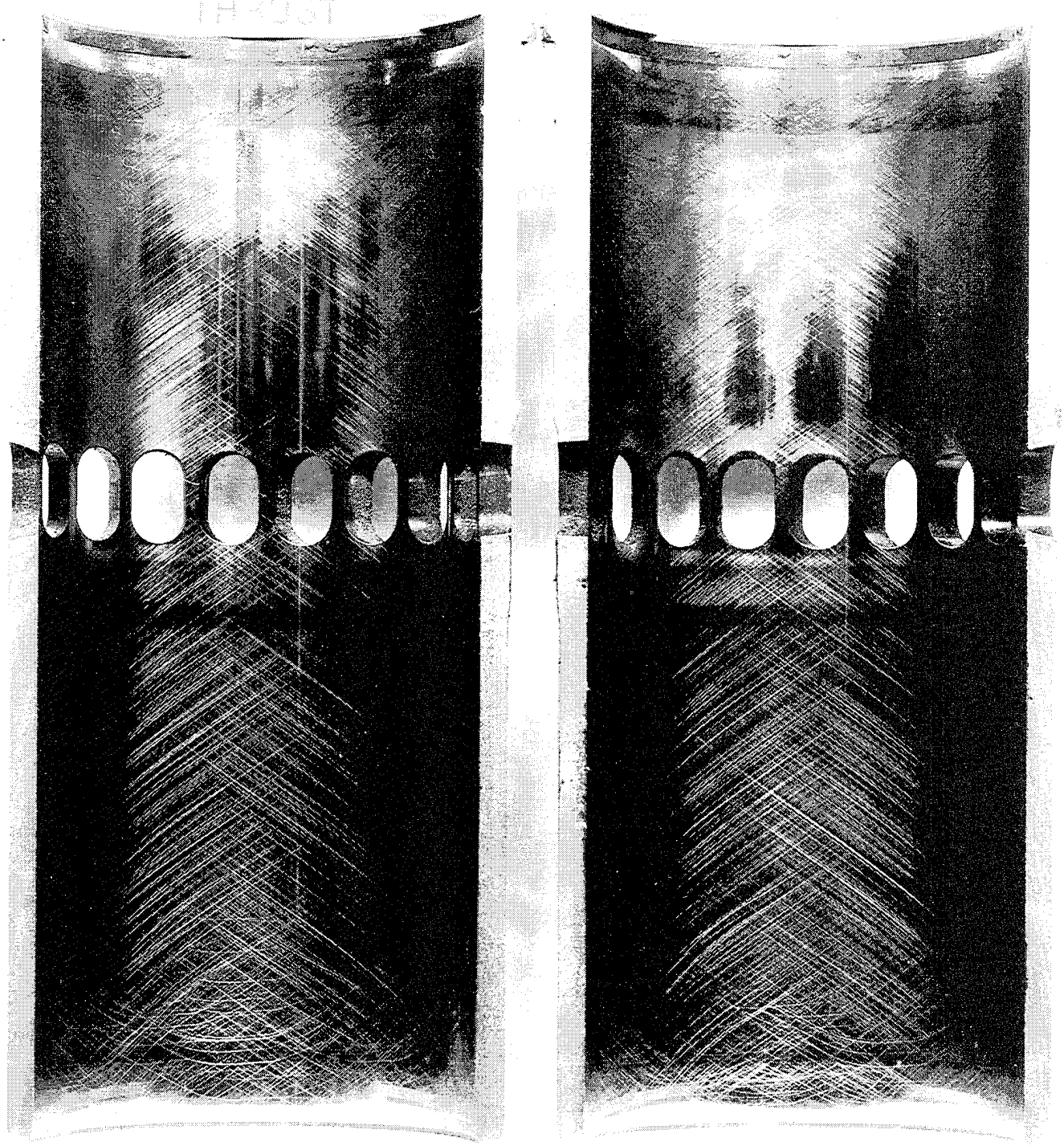

6V53T (#54)
1-R


6V53T (#54)
1-P
THRUST


6V53T (#54)
2-R
THRUST



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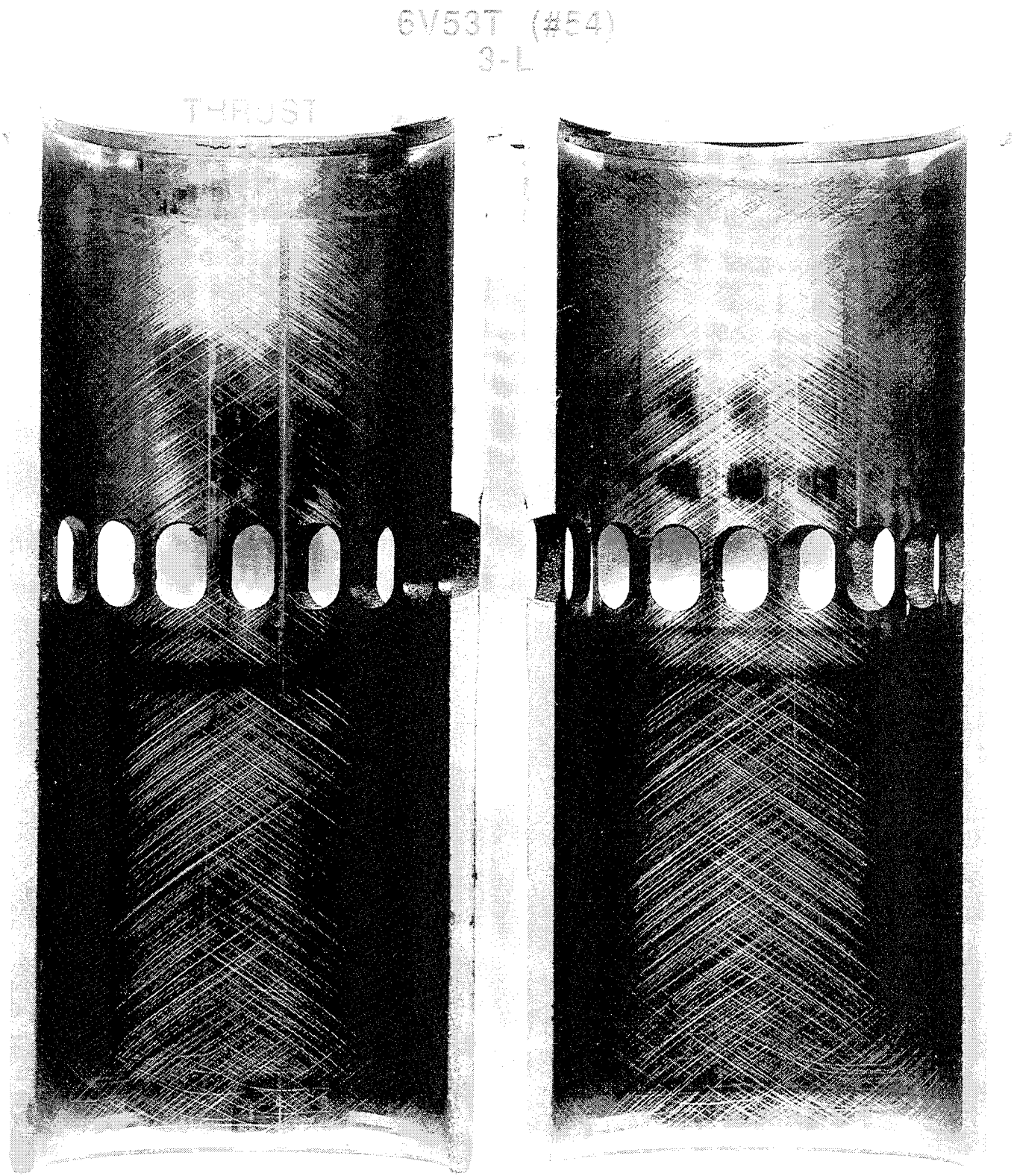
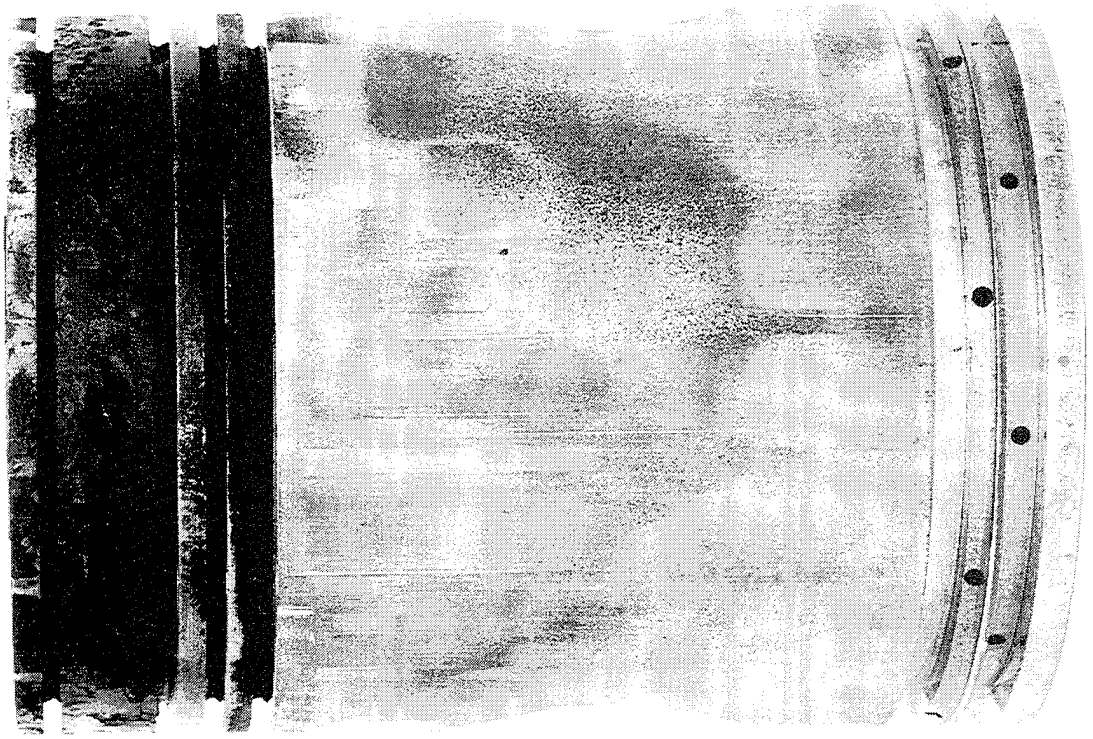

6V53T (#54)
3-L
THRUST

6V53T (#54)
1-R-AT



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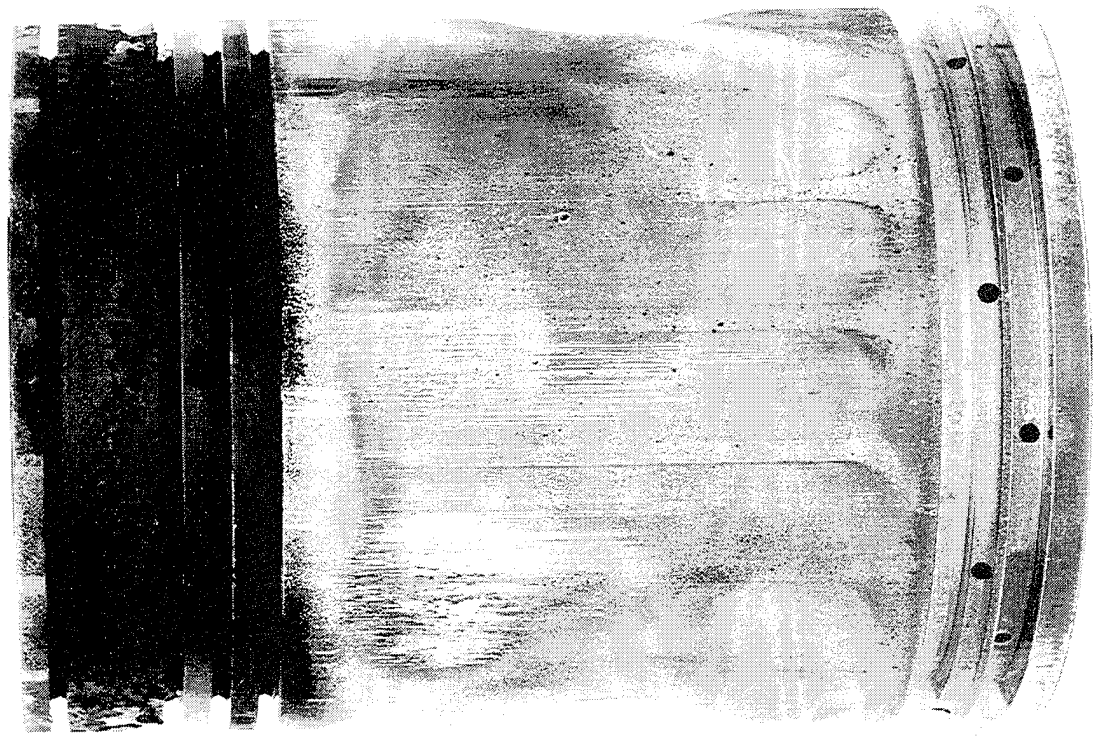
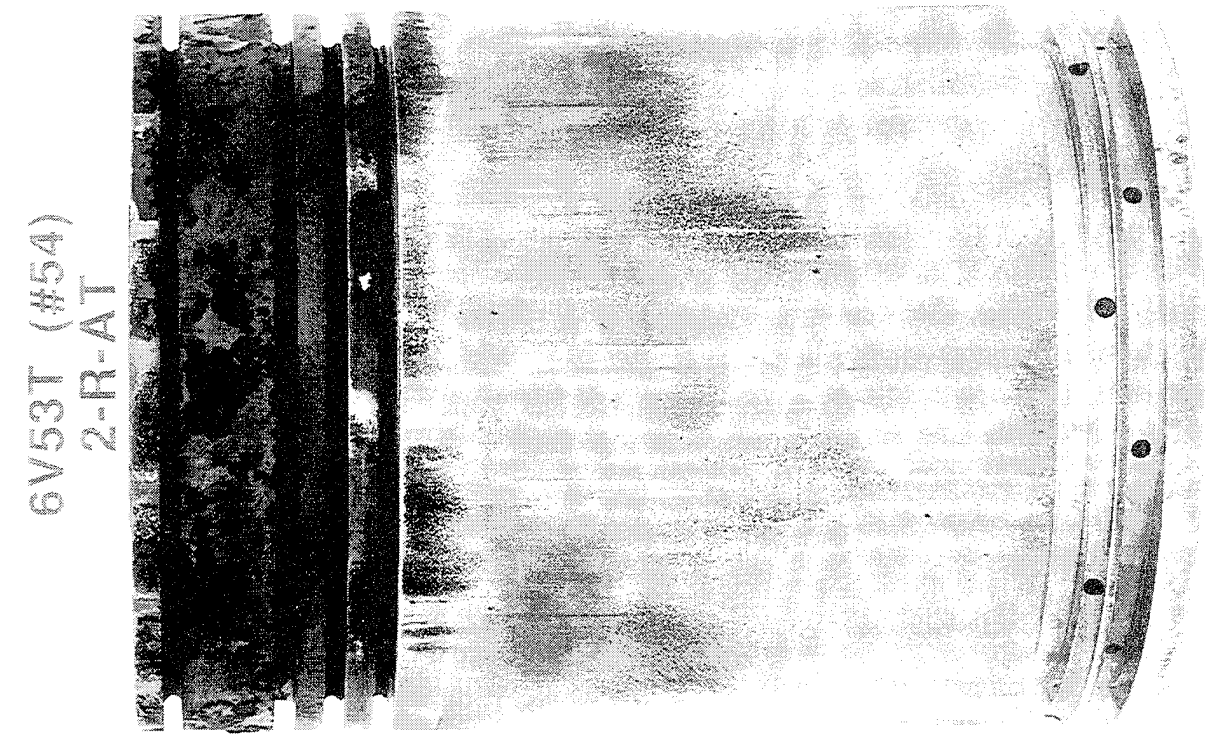
1-R-T

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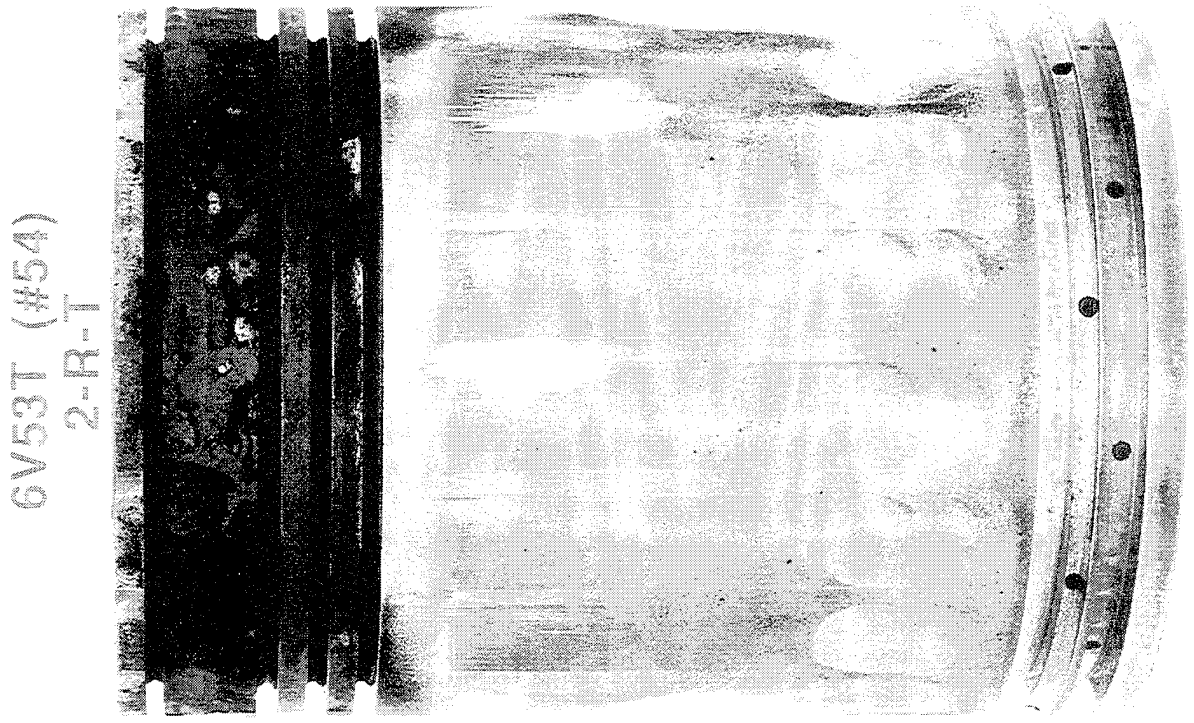
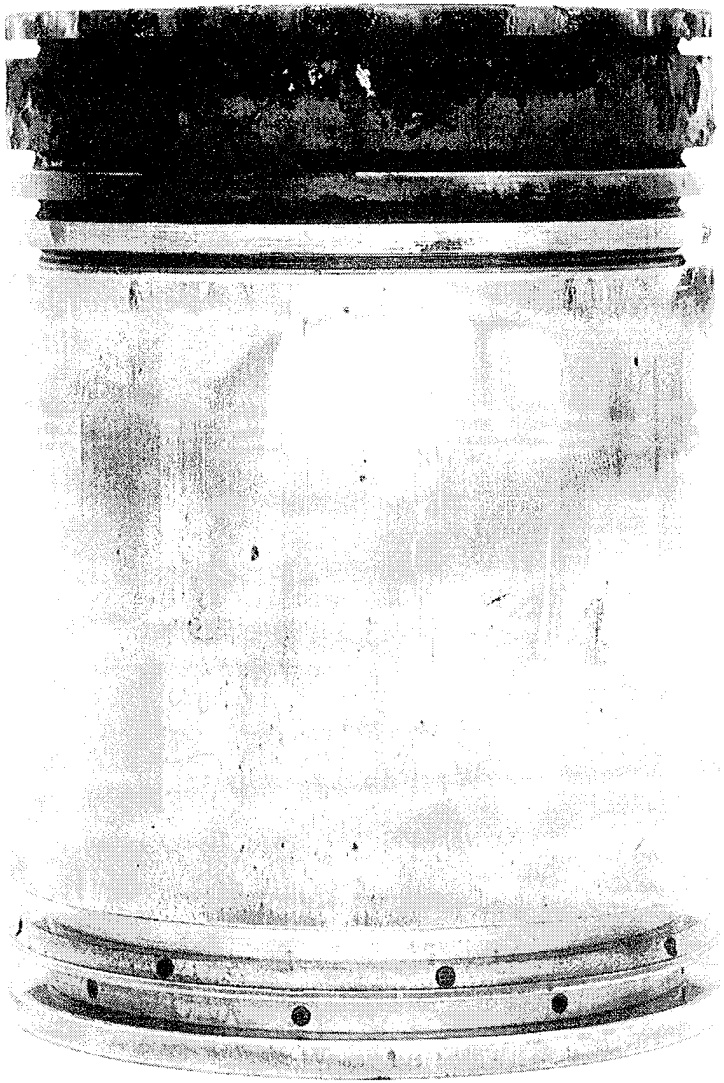
2-R-AT


6V53T (#54)
2-R-T

6V53T (#54)
3-R-T

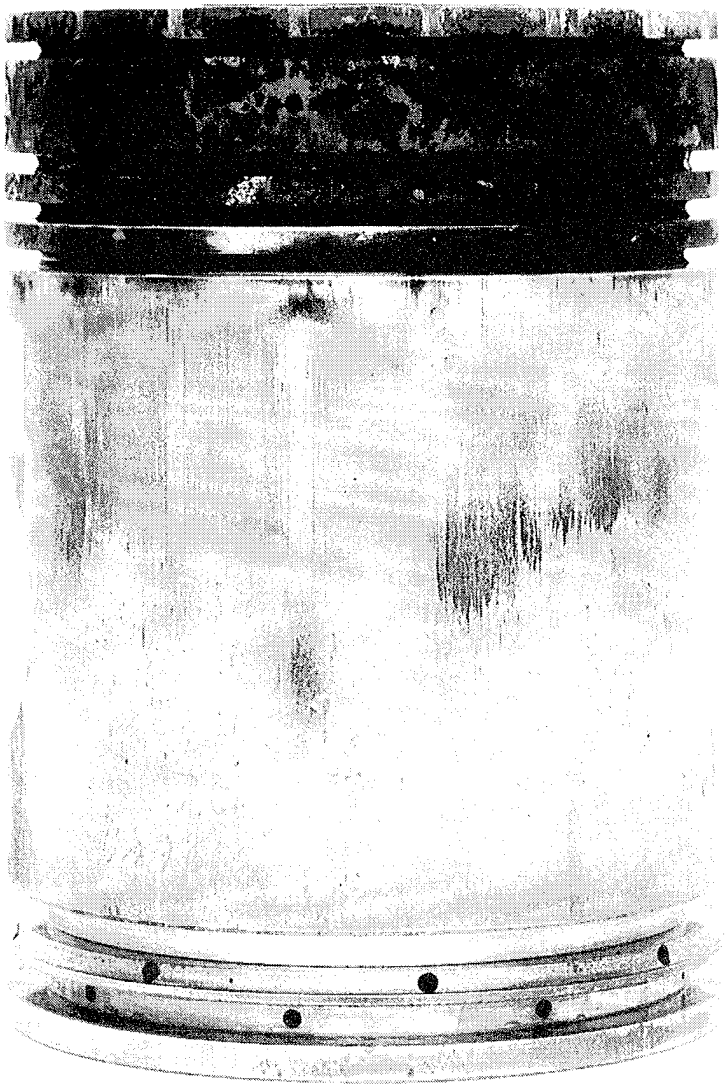
6V53T (#54)
3-R-AT

6V53T (#54)
1-L-T



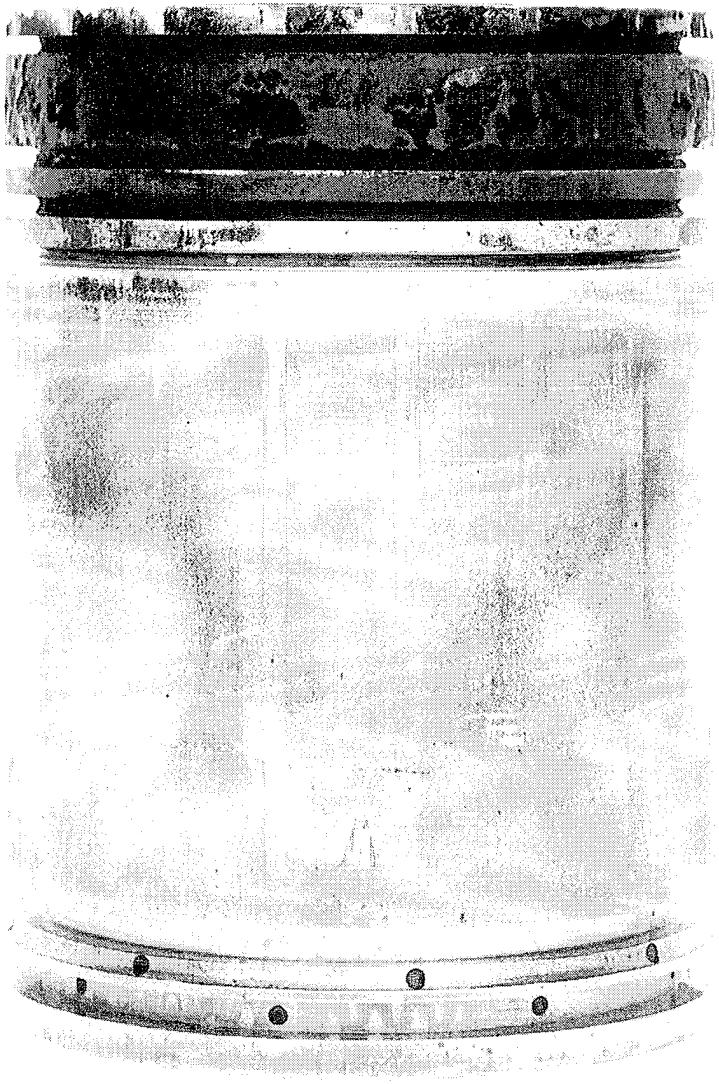
6V53T (#54)
1-L-AT

6V53T (#54)
2-L-T



6V53T (#54)
2-L-AT

6V53T (#54)
3-L-T



6V53T (#54)
3-L-AT

APPENDIX B

Test 6V-53T — 56A

Lubricant "B"
AL-19528-L

6V-53T
Test 56A
ENGINE REBUILD MEASUREMENTS
Lubricant: AL-19528-L

	Min		Max		Avg		Specified Limits		
	mm	in.	mm	in.	mm	in.	mm (in.)	-	mm (in.)
CYLINDER BLOCK BORE									
Inside Diameter (Bottom)	110.651	4.3565	110.686	4.3579	110.666	4.3571	110.655 (4.3565)	-	110.681 (4.3575) New
								-	110.731 (4.3595) Max
Out-of-Round	0.000	0.0000	0.036	0.0014	0.009	0.0004			
Taper	0.000	0.0000	0.028	0.0011	0.009	0.0003		-	0.038 (0.0015) Max
								-	0.038 (0.0015) Max
CYLINDER LINERS (Installed)									
Inside Diameter	98.426	3.8752	98.467	3.8768	98.446	3.8760	98.430 (3.8752)	-	98.468 (3.8767)
Out-of-Round	0.000	0.0000	0.015	0.0006	0.008	0.0003		-	0.038 (0.0015) Max
Taper	0.003	0.0001	0.015	0.0006	0.008	0.0003		-	0.038 (0.0015) Max
Piston Diameter (at Skirt)	98.241	3.8679	98.251	3.8683	98.246	3.8681	98.219 (3.8669)	-	98.775 (3.8691)
Piston Skirt-to-Cylinder Liner Clearance	0.178	0.0070	0.221	0.0087	0.201	0.0079	0.155 (0.0061)	-	0.249 (0.0098)
COMPRESSION RINGS									
Gap (No. 1, Fire Ring)	0.66	0.026	0.89	0.035	0.80	0.032	0.51 (0.020)	-	1.0 (0.040)
Gap (Nos. 2, 3, 4)	0.66	0.026	0.79	0.031	0.72	0.028	0.51 (0.020)	-	1.0 (0.040)
RING-TO-GROOVE CLEARANCE									
Top (No. 1, Fire Ring)	0.076	0.0030	0.102	0.0040	0.087	0.0034	0.08 (0.0030)	-	0.17 (0.0066)
No. 2, Compression Ring	0.203	0.0080	0.216	0.0085	0.212	0.0083	0.18 (0.0070)	-	0.27 (0.0105)
Nos. 3 and 4, Compression Rings	0.127	0.0050	0.165	0.0065	0.150	0.0059	0.13 (0.0050)	-	0.22 (0.0085)
OIL CONTROL RINGS (Nos. 5, 6, 7)									
Gap	0.279	0.0110	0.381	0.0150	0.340	0.0134	0.254 (0.0100)	-	0.508 (0.020)
Ring-to-Groove Clearance	0.063	0.0025	0.102	0.0040	0.076	0.0030	0.038 (0.0015)	-	0.140 (0.0055)
PISTON PIN									
Pin-to-Piston Bushing Clearance	0.071	0.0028	0.081	0.0032	0.075	0.0029	0.064 (0.0025)	-	0.864 (0.0034)
Pin-to-Connecting Rod Bushing Clearance	0.030	0.0012	0.038	0.0015	0.034	0.0013	0.025 (0.0010)	-	0.048 (0.0019)
Connecting Rod Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.028 (0.0011)	-	0.104 (0.0041)
Main Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.076 (0.0030)	-	0.127 (0.0050)
Camshaft Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.114 (0.0045)	-	0.152 (0.0060)

6V-53T
Test 56A
240-HR TRACKED VEHICLE CYCLE ENDURANCE TEST — OPERATING CONDITIONS SUMMARY
Lubricant: AL-19528-L
Fuel: Reference No. 2 Diesel Fuel

	Maximum Power Mode, 2,800 rpm		Maximum Torque Mode, 2,200 rpm	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	2,801	2	2,201	2
Torque, N-m (lb-ft)	758 (554)	1 (1)	852 (623)	0.43 (1)
Fuel Consumption, kg/hr (lb/hr)	53.17 (117.4)	0.594 (1.3)	46.17 (101.9)	1.41 (3.1)
Observed Power, kW (bhp)	220 (296)	0 (1)	195 (261)	0 (0)
BSFC, g/kW-hr (lb/bhp-hr)	0.241 (0.397)	0.003 (0.004)	0.237 (0.391)	0.007 (0.0120)
Temperatures, °C (°F)				
Exhaust Before Turbo	504 (939)	35 (63)	503 (937)	41 (74)
Exhaust After Turbo	415 (779)	10 (18)	430 (806)	13 (24)
Water Jacket Inlet	72 (161)	1 (1)	72 (161)	1 (1)
Water Jacket Outlet	77 (170)	0 (1)	77 (170)	0 (1)
Oil Sump	110 (231)	2 (3)	105 (221)	2 (4)
Fuel at Filter	35 (95)	1 (1)	35 (94)	1 (2)
Inlet Air	32 (89)	1 (2)	32 (90)	1 (2)
Airbox	138 (280)	3 (5)	109 (229)	2 (3)
Air After Compressor	125 (258)	3 (6)	105 (220)	3 (5)
Blowby	54 (129)	3 (5)	45 (112)	3 (6)
Oil Gallery	99 (210)	3 (5)	94 (201)	2 (4)
Wet Bulb Temperature	19 (66)	2 (3)	17 (63)	7 (12)
Dry Bulb Temperature	28 (83)	3 (6)	27 (80)	2 (4)
Pressures				
Exhaust Before Turbo, kPa (psi)	90.69 (13.2)	2.900 (0.42)	61.21 (8.9)	1.596 (0.23)
Compressor Discharge, kPa (psi)	91.25 (13.2)	3.411 (0.49)	68.54 (9.9)	2.458 (0.36)
Blower Discharge, kPa (psi)	113.7 (16.5)	4.109 (0.60)	69.8 (10.1)	2.520 (0.37)
Fuel Transfer Pump, kPa (psi)	476.5 (69.1)	1.144 (0.17)	454.2 (65.9)	1.052 (0.15)
Oil Gallery, kPa (psi)	271.0 (39.3)	5.579 (0.81)	236.3 (34.3)	8.324 (1.21)
Intake Vacuum, kPa (in. Hg)	27.34 (28.1)	0.721 (0.21)	16.98 (25.0)	0.500 (0.15)
Barometric Pressure, kPa (in. Hg)	98.06 (29.0)	0.814 (0.24)	97.94 (28.9)	0.698 (0.21)
Exhaust Common, kPa (in. H_2O)	5.073 (20.4)	0.224 (0.90)	3.571 (14.3)	0.162 (0.65)
Blowby, kPa (in. H_2O)	0.264 (1.1)	0.037 (0.15)	0.090 (0.4)	0.012 (0.05)

6V-53T
Test 56A
LUBRICANT ANALYSIS
Lubricant: AL-19528-L

Lubricant Analysis	ASTM Test Method	Test Time, hr 0	120	151.5
Kinematic Viscosity, cSt, at				
40°C	D 445	54.78	ND*	48.32
100°C	D 445	11.01	9.50	9.31
Total Acid Number, mg KOH/g	D 664	2.60	1.80	2.38
Total Base Number, mg KOH/g	D 664	6.40	ND	3.85
Pentane B Insolubles, wt%	D 893	NIL	ND	0.03
Toluene B Insolubles, wt%	D 893	NIL	ND	0.03
Flash Point, °C	D 92	221	ND	216

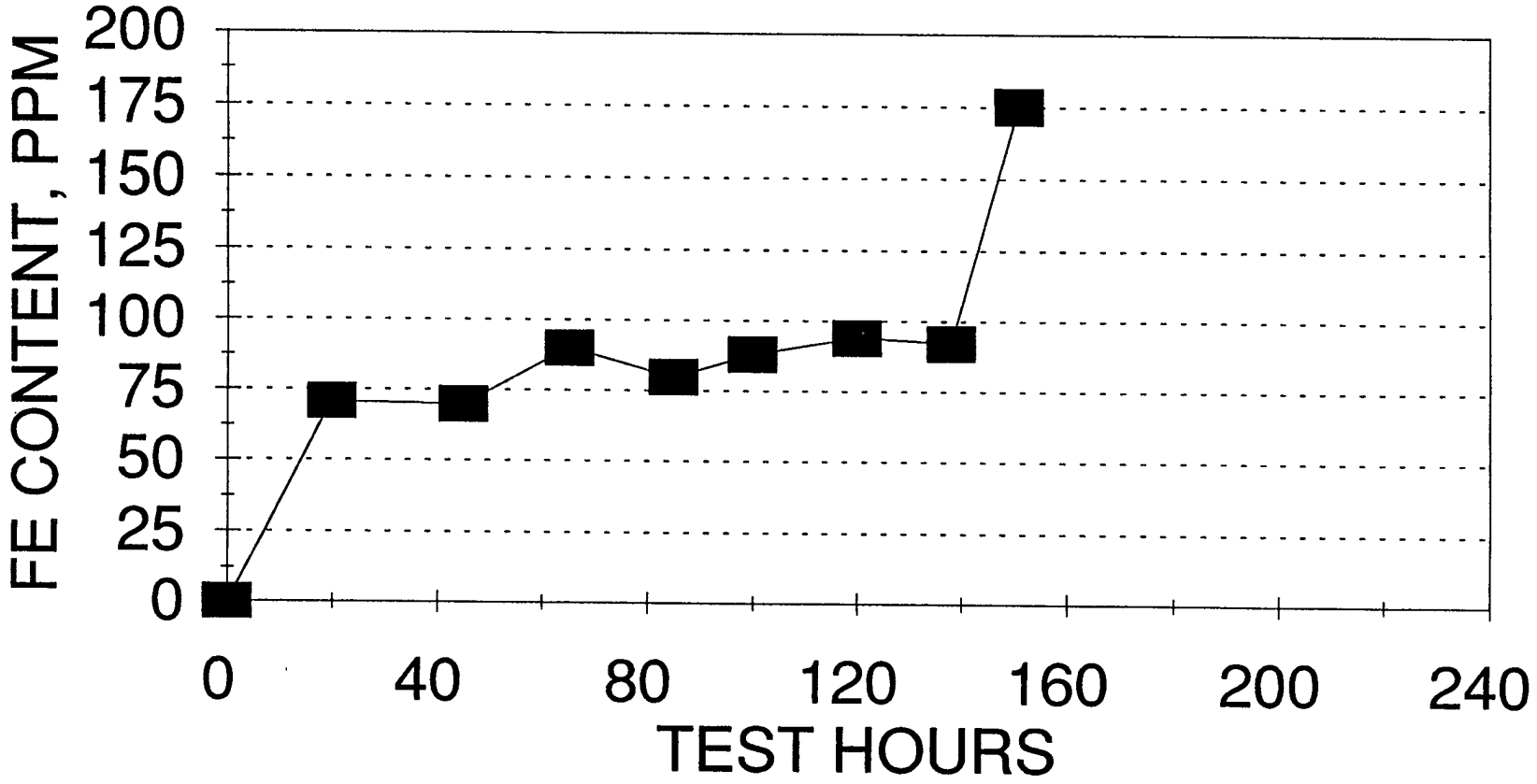
* ND = Not Determined

6V-53T
Test 56A
TOTAL OIL CONSUMPTION AND WEAR METALS BY XRF
Lubricant: AL-19528-L

Test Time, hr	Total Oil Consumed kg	lb	Wear Metals, ppm Fe	Cu
0	--	--	<20	<20
20	2.99	6.59	71	<20
45	12.19	26.87	70	<20
65	17.74	39.12	90	<20
85	23.68	52.20	80	<20
100	26.83	59.15	88	<20
120	29.47	64.96	94	<20
137.5	32.23	71.05	92	<20
151.5	35.08	77.34	175	<20
	kg/hr	lb/hr		
Average Oil Consumption Rate	0.23	0.51		

USED OIL IRON CONTENT

6V53T TEST #56A AL-19528



6V-53T
Test 56A
POST-TEST ENGINE CONDITIONS AND DEPOSITS
Lubricant: AL-19528-L

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Avg
CYLINDER LINER							
Intake Port Plugging							
% Restriction	<1	<1	<1	<1	<1	<1	<1
Liner Scuffing, % Area							
Thrust	0	0	29	100	95	62	47.67
Antithrust	11	1	24	100	100	42	46.33
% Total Area	5.5	0.5	26.5	100.0	97.5	52	47.00
						Overall:	47.00
						Overall, Five Cylinders (w/o 2R):	36.90
% Area Bore Polished							
Thrust	2	8	6	0	0	2	3.00
Antithrust	19	5	5	0	0	3	5.33
% Avg Area Bore Polished	10.5	6.5	5.5	0	0	2.5	4.17
						Overall:	4.17
						Overall, Five Cylinders (w/o 2R):	5.00
Avg Liner Distress	11.5	0.5	26.5	100	97.5	52	48.00
						Overall, Five Cylinders (w/o 2R):	38.10
RINGS							
Ring Face Distress, Demerits							
No. 1	4.75	1.50	3.50	75.00	75.00	72.50	38.71
No. 2	11.25	3.25	10.25	70.00	75.00	72.50	40.38
No. 3	17.75	1.25	6.50	70.00	75.00	65.00	39.25
No. 4	13.00	1.75	12.50	47.50	62.50	66.25	33.92
						Overall:	38.06
PISTONS							
Piston Skirt Rating*							
Thrust	S	S	3% SC & S	30% SC, 1% PM & S	58% SC & S	20% SC & S	
Antithrust	7% SC & S	S	2% SC & S	7% SC, 1% PM & S	32% SC & S	7% SC & S	
Piston WTD Rating**	207.87	216.62	197.88	169.63	224.75	223.37	
Ring Sticking***							
No. 1	F	F	F	F, PC	BR	F	
No. 2	F	F	F	F	F, TC	F	
No. 3	F	F	F	F	F, TC	F	
No. 4	F	F	F	F	F	F	
EXHAUST VALVES							
Deposits							
Head+	40 HC, 5 MC 55 LC	60 HC, 25 MC 15 LC	40 HC, 30 MC 30 LC	15 HC, 55 MC 30 LC	60 HC, 20 MC 20 LC	50 HC, 30 MC 20 LC	
Face	← Light Amount of Carbon and Ash Embedment →						
Tulip++	1.0	1.0	1.0	1.0	1.0	1.0	
Stem	← All Stems 5 to 15% #9 Lacquer →						
Surface Conditions							
Freeness in Guide	← Normal →						
Head	← Normal →						
Face	← Normal →						
Seat	← Normal →						
Stem	← Normal →						
Tip	← Normal →						

* Lt = Light, S = Scratches, PM = Plating Melted, N = Normal, SC = Scuffing, and B = Burn

** CRC Weighted Total Deposits (0 = Least, 900 = Most)

*** F = Free, PC = Partially Collapsed, TC = Totally Collapsed, BR = Broken, and CS = Cold Stuck

\+ HC = Hard Carbon, LC = Light Carbon, MC = Medium Carbon — the number indicates percentage

++ The higher the number, the darker the lacquer (0 = Lightest, 9 = Darkest)

6V-53T
Test 56A
LINER AND RING FACE DISTRESS SUMMARY
Lubricant: AL-19528-L

Liner Distress

Six-Cylinder Avg	48.0
Five-Cylinder Avg (w/o 2R)	38.1
Five-Cylinder Avg (w/o 3R)	47.2

Ring Face Distress, Nos. 2 and 3

Six-Cylinder Avg	39.81
Five-Cylinder Avg (w/o 2R)	32.78
Five-Cylinder Avg (w/o 3R)	34.03

Both 2R and 3R were replaced at 20 hours.

6V-53T
Test 56A
WEAR MEASUREMENTS
Lubricant: AL-19528-L

Cylinder Liner Bore Diameter Changes

	Cylinder Number											
	1L				2L				3L			
	T-AT*		F-B		T-AT		F-B		T-AT		F-B	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Top	0.018	0.0007	–0.003	–0.0001	0.005	0.0002	0.008	0.0003	0.008	0.0003	0.013	0.0005
Middle	0.010	0.0004	0.025	0.0010	0.003	0.0001	0.008	0.0003	0.010	0.0004	0.008	0.0003
Bottom	0.010	0.0004	–0.008	–0.0003	0.003	0.0001	0.003	0.0001	0.010	0.0004	0.000	0.0000

	Cylinder Number											
	1R				2R				3R			
	T-AT		F-B		T-AT		F-B		T-AT		F-B	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Top	0.046	0.0018	0.025	0.0010	0.000	0.0000	0.003	0.0001	0.023	0.0009	0.030	0.0012
Middle	0.023	0.0009	0.020	0.0008	0.008	0.0003	0.003	0.0001	0.010	0.0004	0.028	0.0011
Bottom	0.003	0.0001	0.005	0.0002	0.005	0.0002	–0.005	–0.0002	0.003	0.0001	–0.003	–0.0001

Average Change

	T-AT		F-B	
	mm	in.	mm	in.
Top	0.017	0.0006	0.013	0.0005
Middle	0.011	0.0004	0.015	0.0006
Bottom	0.006	0.0002	–0.001	–0.0000

Piston Ring End Gap Change

	Cylinder Number													
	1L		2L		3L		1R		2R		3R		Average Change	
Ring No.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
1	0.051	0.0020	0.025	0.0010	–0.025	–0.0010	0.305	0.0120	–0.838	–0.0330	0.051	0.0020	–0.072	–0.0028
2	0.025	0.0010	0.025	0.0010	0.000	0.0000	0.178	0.0070	–0.737	–0.0290	0.025	0.0010	–0.080	–0.0032
3	0.000	0.0000	0.000	0.0000	–0.013	–0.0005	0.076	0.0030	–0.711	–0.0280	0.000	0.0000	–0.108	–0.0043
4	–0.025	–0.0010	–0.025	–0.0010	0.000	0.0000	0.051	0.0020	0.533	0.0210	0.000	0.0000	0.089	0.0035
5	0.051	0.0020	0.127	0.0050	0.076	0.0030	0.152	0.0060	0.203	0.0080	0.102	0.0040	0.119	0.0047
6	0.051	0.0020	0.178	0.0070	0.152	0.0060	0.178	0.0070	0.127	0.0050	0.051	0.0020	0.123	0.0048
7	–0.025	–0.0010	0.127	0.0050	0.178	0.0070	0.152	0.0060	0.076	0.0030	0.051	0.0020	0.093	0.0037

Overall Average Change

mm	in.
0.023	0.0009

* T-AT = Thrust-Antithrust, F-B = Front-Back

6V-53T RING FACE DISTRESS
(Six Cylinders)

Sponsor Code: AL-19528-L
Hours: 151.5

Date: 03-22-91

SwRI Code: BFLRF
Block: 01 Test 56A

Cylinder No.	Ring No.	Extreme (1.00)		Heavy (0.75)		Medium (0.50)		Light (0.25)		Totals	
		% Area	Demerits	% Area	Demerits	% Area	Demerits	% Area	Demerits	% Area	Demerits
1L	1	0	0.00	2	1.50	0	0.00	13	3.25	15	4.75
	2	0	0.00	2	1.50	3	1.50	33	8.25	38	11.25
	3	0	0.00	1	0.75	4	2.00	60	15.00	65	17.75
	4	0	0.00	3	2.25	4	2.00	35	8.75	42	13.00
2L	1	0	0.00	0	0.00	1	0.50	4	1.00	5	1.50
	2	0	0.00	0	0.00	0	0.00	13	3.25	13	3.25
	3	0	0.00	0	0.00	0	0.00	5	1.25	5	1.25
	4	0	0.00	0	0.00	0	0.00	7	1.75	7	1.75
3L	1	0	0.00	2	1.50	2	1.00	4	1.00	8	3.50
	2	0	0.00	3	2.25	7	3.50	18	4.50	28	10.25
	3	0	0.00	0	0.00	3	1.50	20	5.00	23	6.50
	4	0	0.00	0	0.00	5	2.50	40	10.00	45	12.50
1R	1	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	2	0	0.00	90	67.50	0	0.00	10	2.50	100	70.00
	3	0	0.00	90	67.50	0	0.00	10	2.50	100	70.00
	4	0	0.00	40	30.00	10	5.00	50	12.50	100	47.50
2R	1	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	2	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	3	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	4	0	0.00	70	52.50	10	5.00	20	5.00	100	62.50
3R	1	0	0.00	95	71.25	0	0.00	5	1.25	100	72.50
	2	0	0.00	95	71.25	0	0.00	5	1.25	100	72.50
	3	0	0.00	80	60.00	0	0.00	20	5.00	100	65.00
	4	0	0.00	80	60.00	5	2.50	15	3.75	100	66.25
3R at 20 hr	1	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	2	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	3	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	4	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	328	232.25	54.67	38.71
2	379	242.25	63.17	40.38
3	393	235.50	65.50	39.25
4	394	203.50	65.67	33.92
2 & 3	772	477.75	64.33	39.81

6V-53T RING FACE DISTRESS
(Five Cylinders)

Sponsor Code: AL-19528-L
Hours: 151.5

Date: 03-22-91

SwRI Code: BFLRF
Block: 01 Test 56A

Cylinder 3R Eliminated

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	228	159.75	45.60	31.95
2	279	169.75	55.80	33.95
3	293	170.50	58.60	34.10
4	294	137.25	58.80	27.45
2 & 3	572	340.25	57.20	34.03

Cylinder 2R Eliminated

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	228	157.25	45.60	31.45
2	279	167.25	55.80	33.45
3	293	160.50	58.60	32.10
4	294	141.00	58.80	28.20
2 & 3	572	327.75	57.20	32.78

6V-53T
PISTON DEMERIT SUMMARY

Sponsor Code: AL-19528-L | SwRI Code: BFLRF
Hours: 151.5 | Date: 03-22-91 | Block: 01 Test 56A

	Piston 1L	Piston 2L	Piston 3L	Piston 1R	Piston 2R	Piston 3R
Carbon (Grooves)	100.00	72.50	85.00	77.50	100.00	102.50
Carbon (Lands)	92.50	122.50	93.75	77.50	123.75	108.75
Lacquer (Grooves)	4.50	10.75	9.00	6.13	0.00	4.75
Lacquer (Lands)	10.87	10.87	10.13	8.50	1.00	7.37
Total Demerits	207.87	216.62	197.88	169.63	224.75	223.37

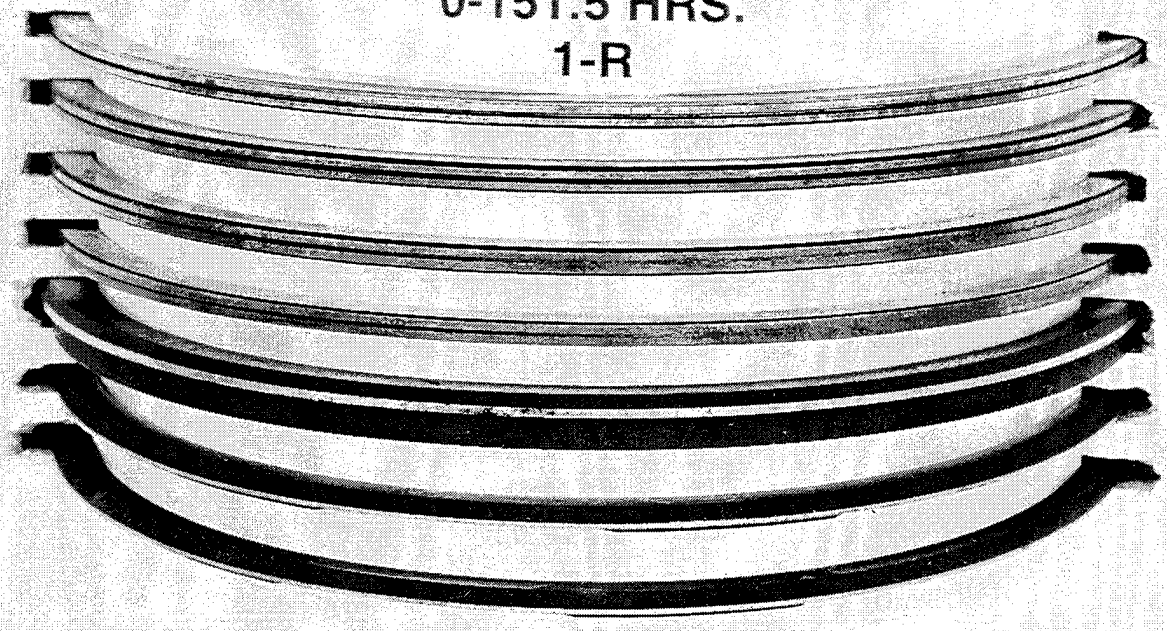
Average of All Six Pistons

Demerits Due to Carbon	1,156.3
Demerits Due to Lacquer	83.87
Total Demerits	1,240.1
Average Demerits	206.69
Average Piston	1L
Worst Piston	2R

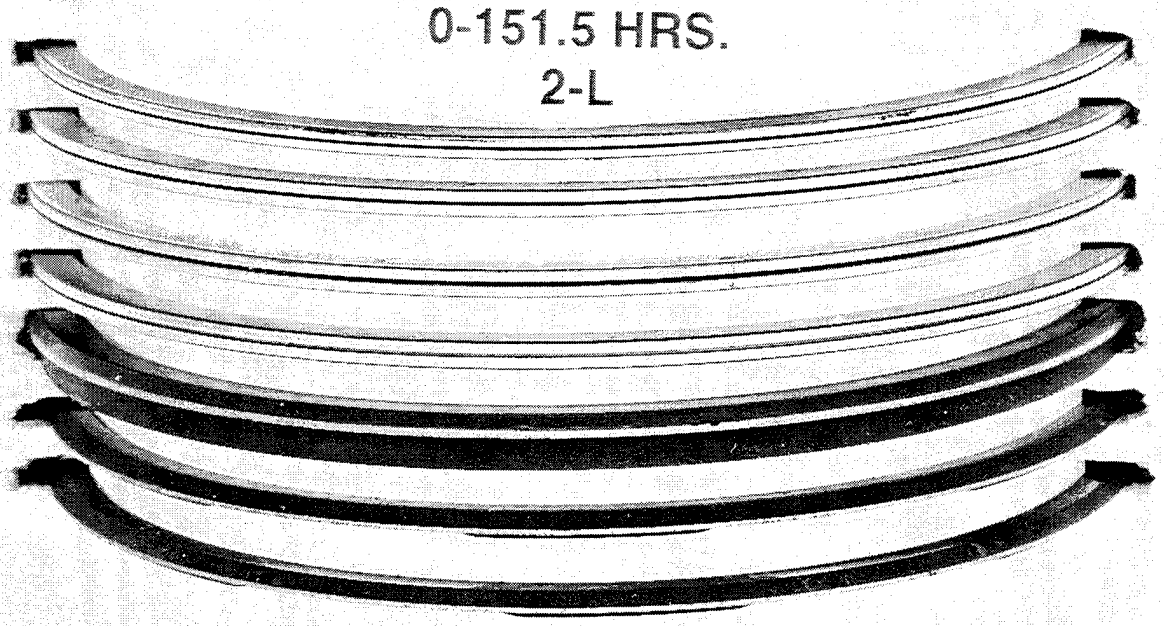
Average of Five Pistons	Excluding 3R	Excluding 2R
Demerits Due to Carbon	945.00	932.55
Demerits Due to Lacquer	71.75	82.87
Total Demerits	1,016.8	1,016.4
Average Demerits	203.35	203.28
Average Piston	1L	1L
Worst Piston	2R	3R

6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
1-L

6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
1-R

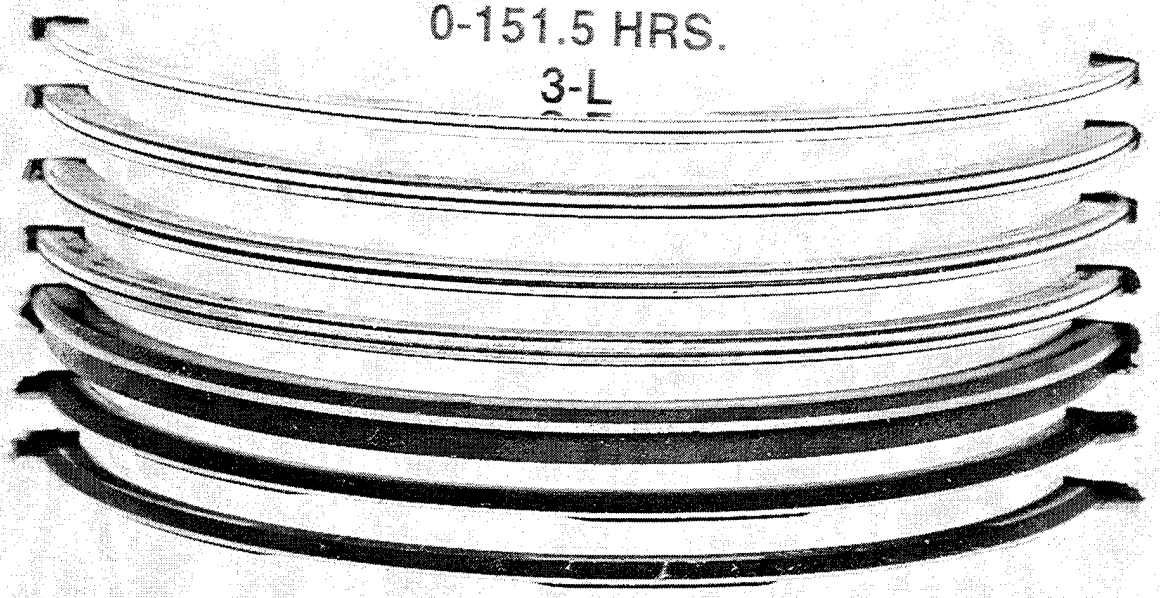


6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
2-L

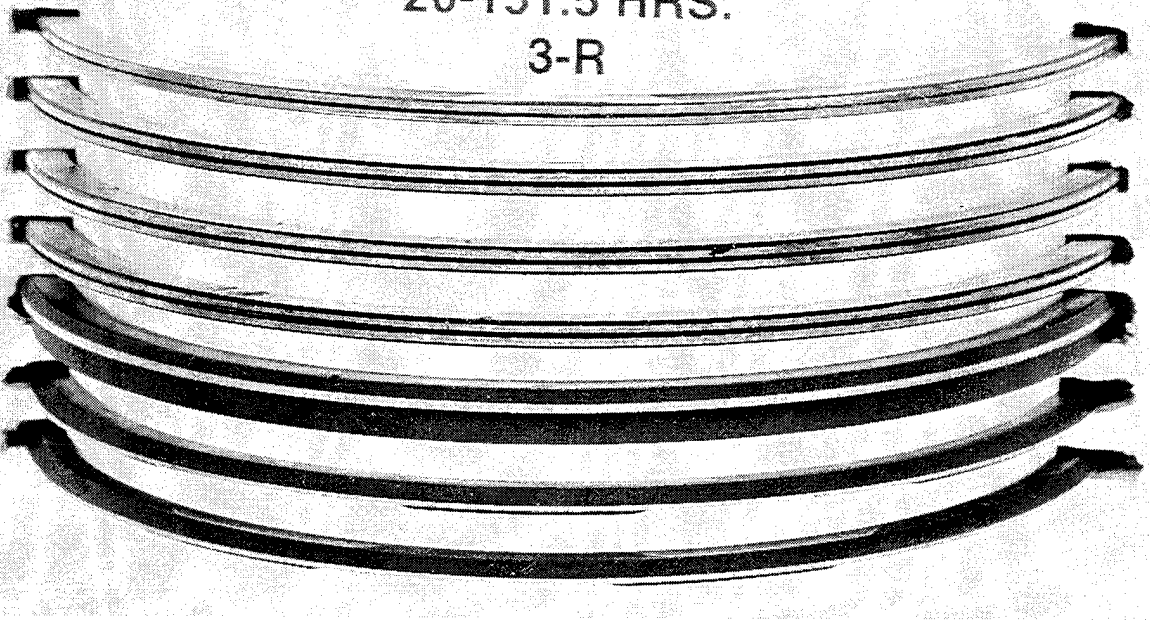


6V53T 56A
AL-19528-L REF DF-2
20-151.5 HRS.
2-R

6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
3-L

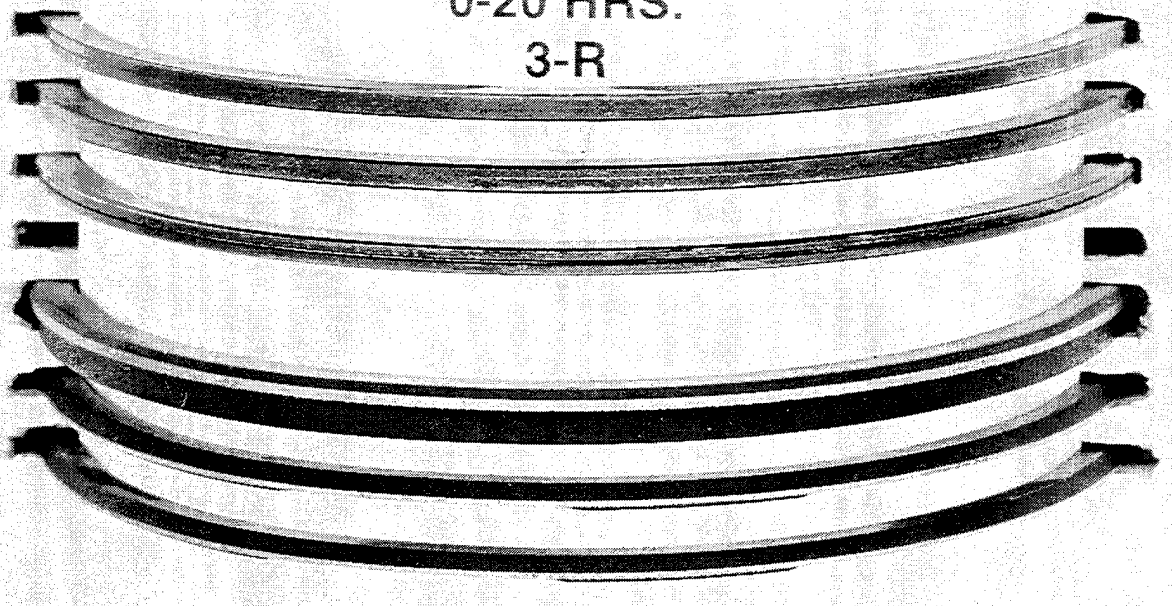


6V53T 56A
AL-19528-L REF DF-2
20-151.5 HRS.
3-R

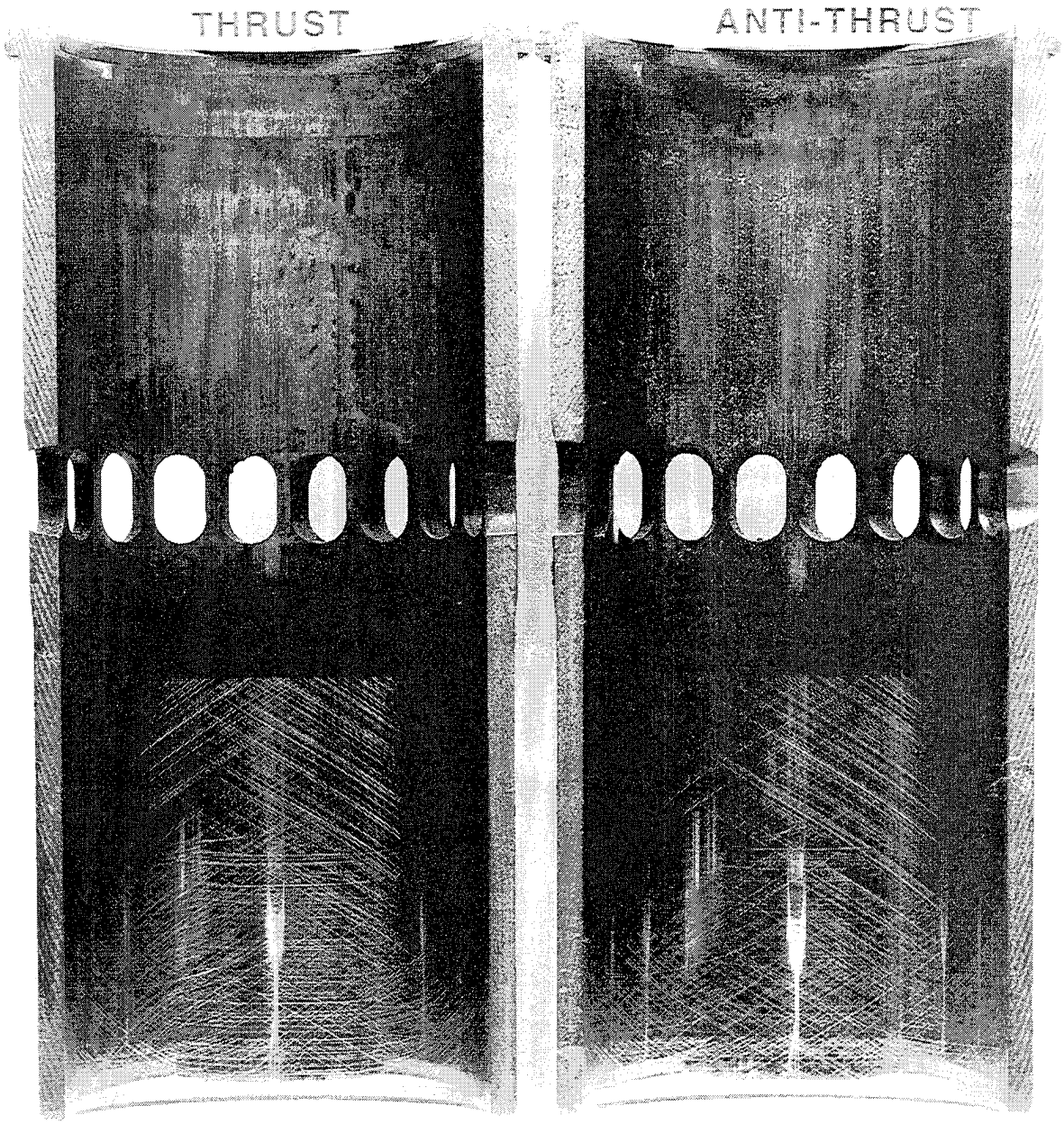


6V53T 56A
AL-19528-L REF DF-2
0-20 HRS.
2-R

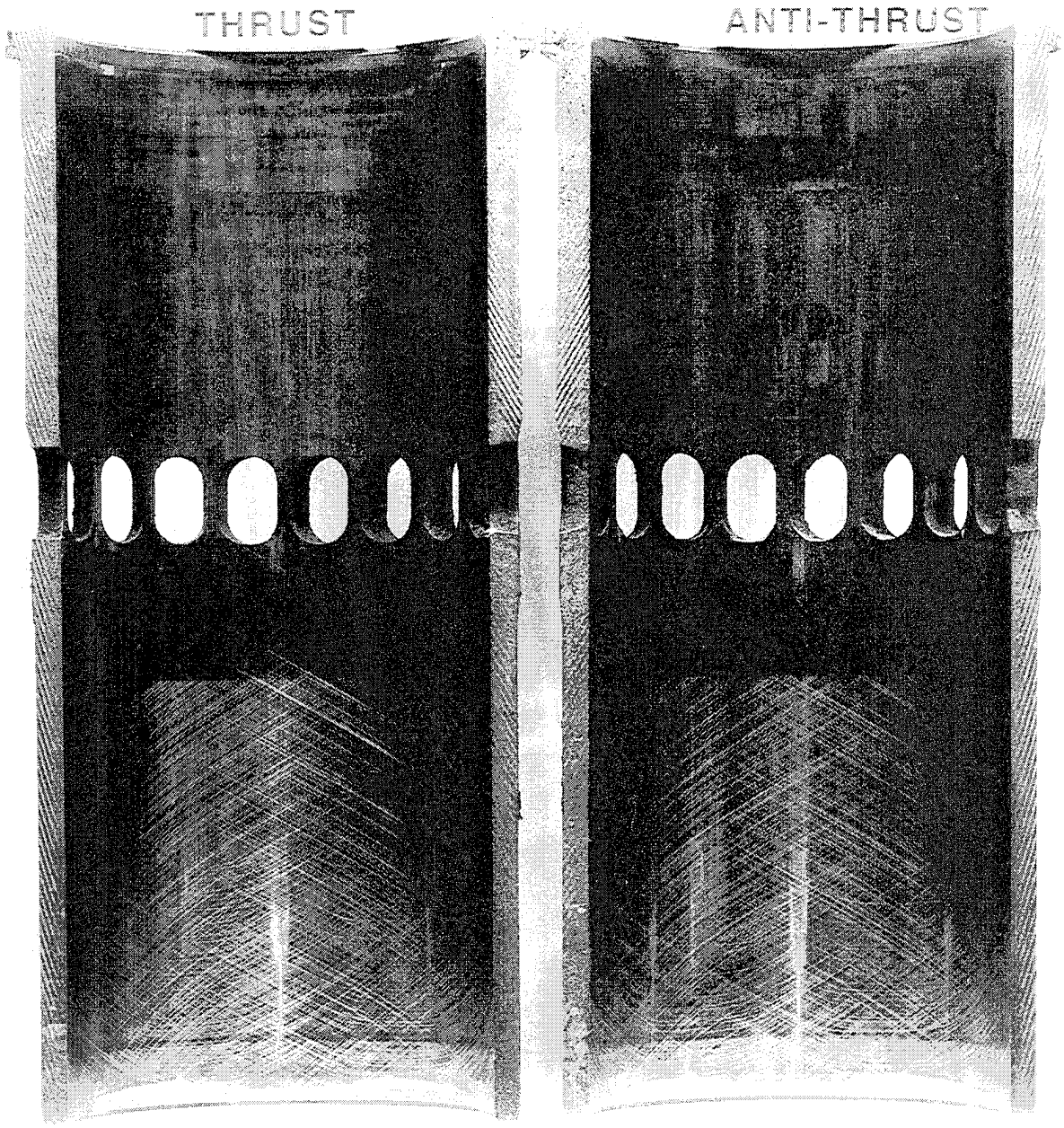
6V53T 56A
AL-19528-L REF DF-2
0-20 HRS.
3-R



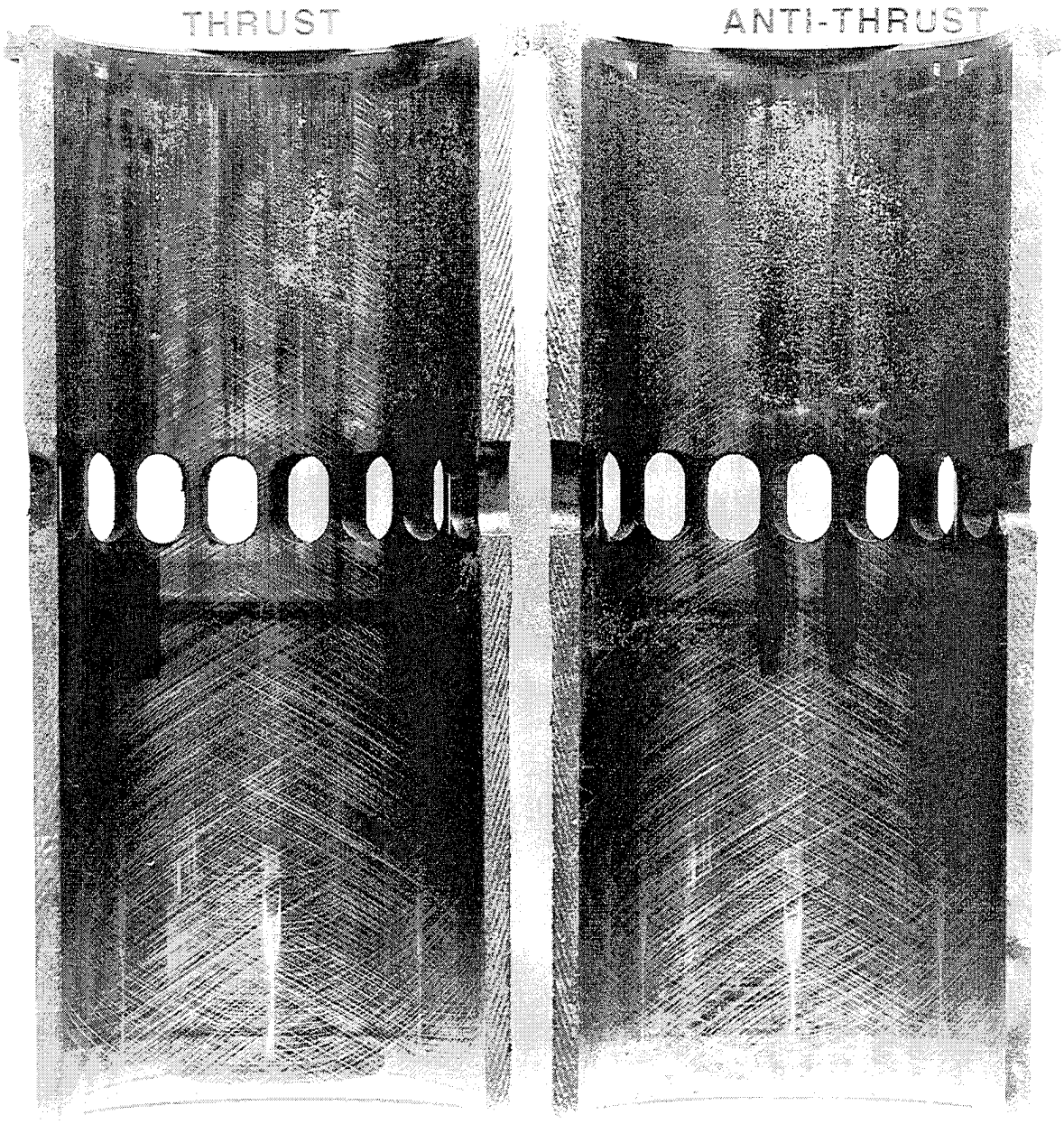
6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
1-R



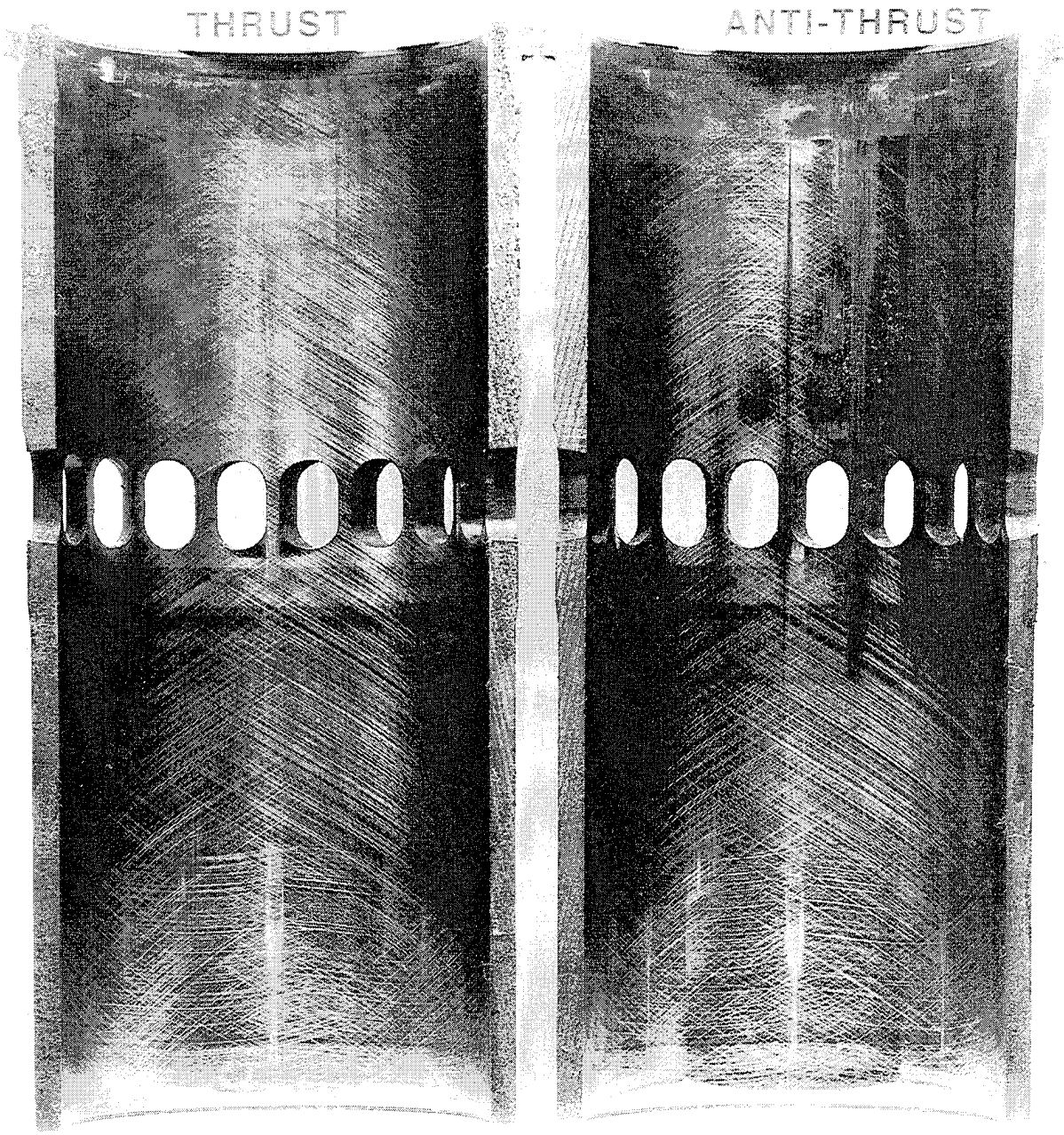
6V53T 56A
AL-19528-L REF DF-2
20-151.5 HRS.
2-R



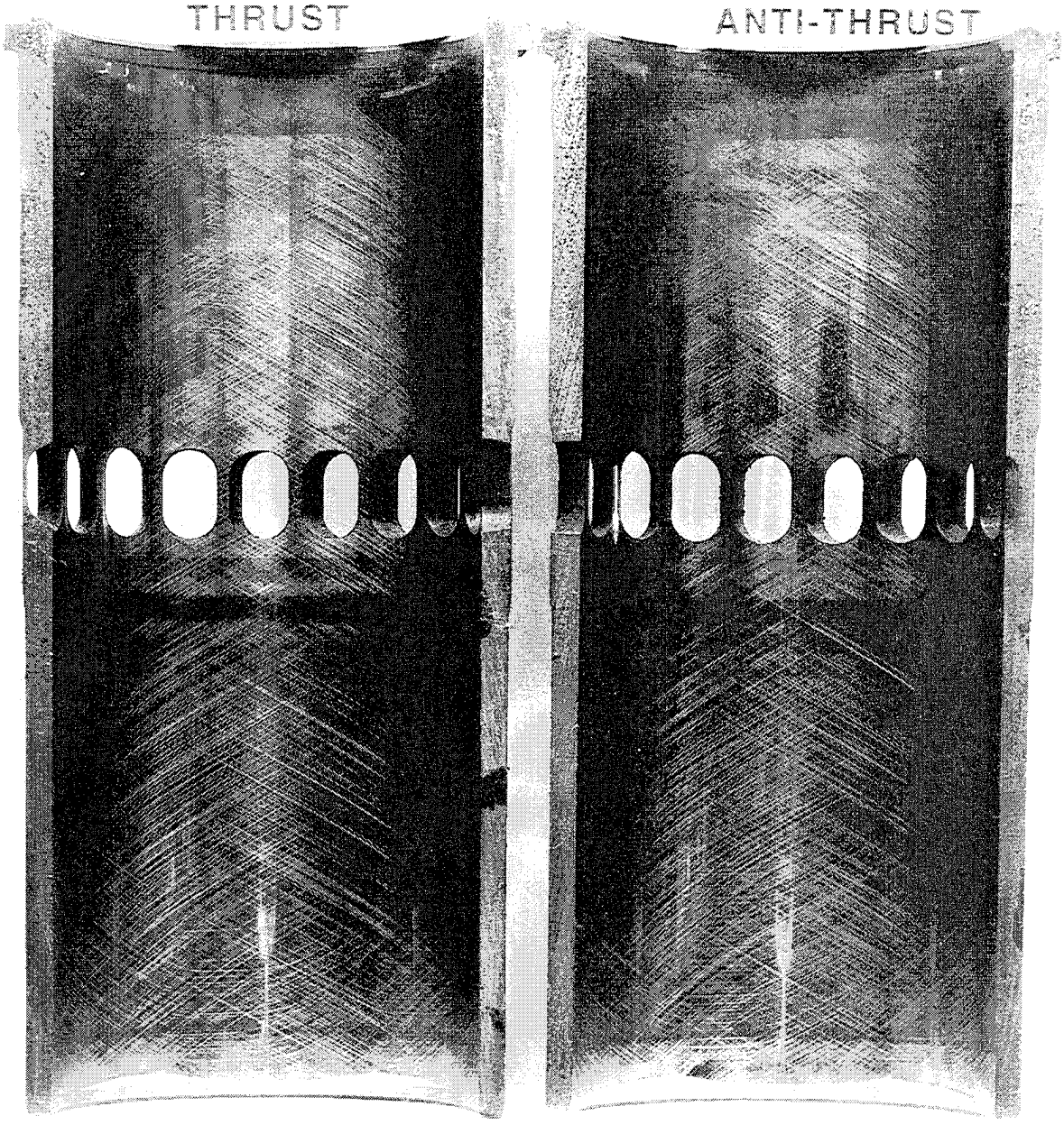
6V53T 56A
AL-19528-L REF DF-2
20-151.5 HRS.
3-R



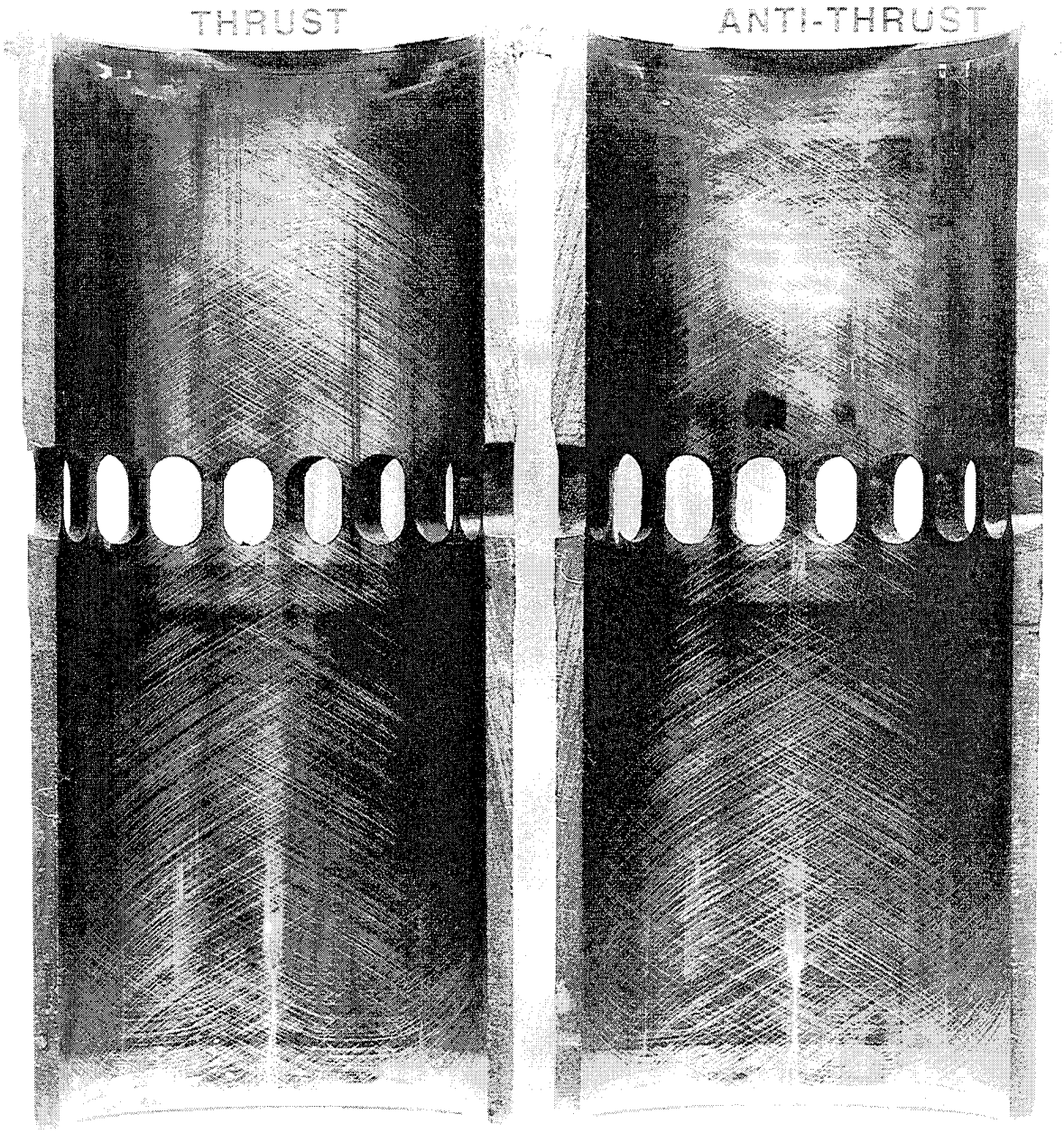
6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
1-L



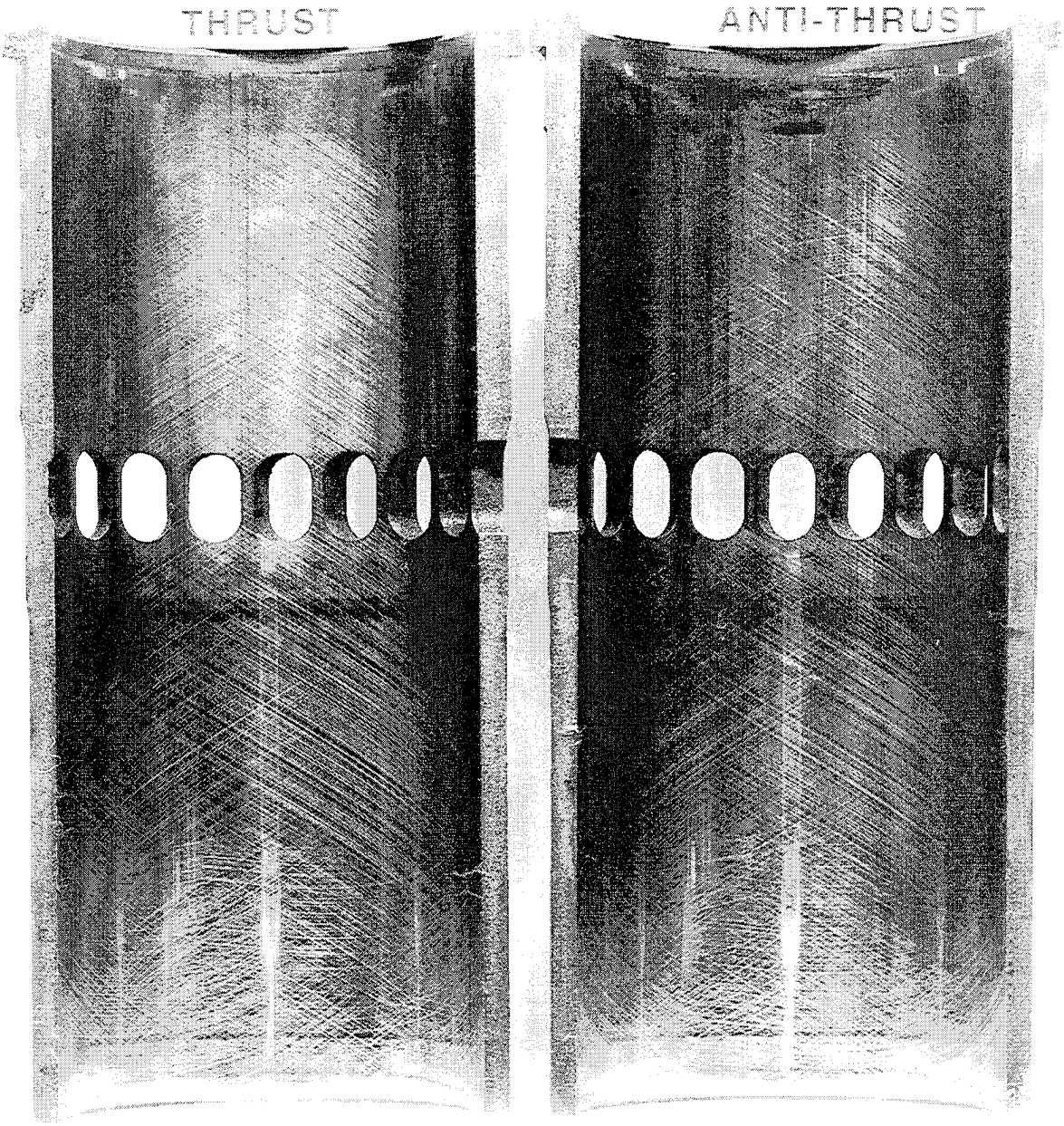
6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
2-L



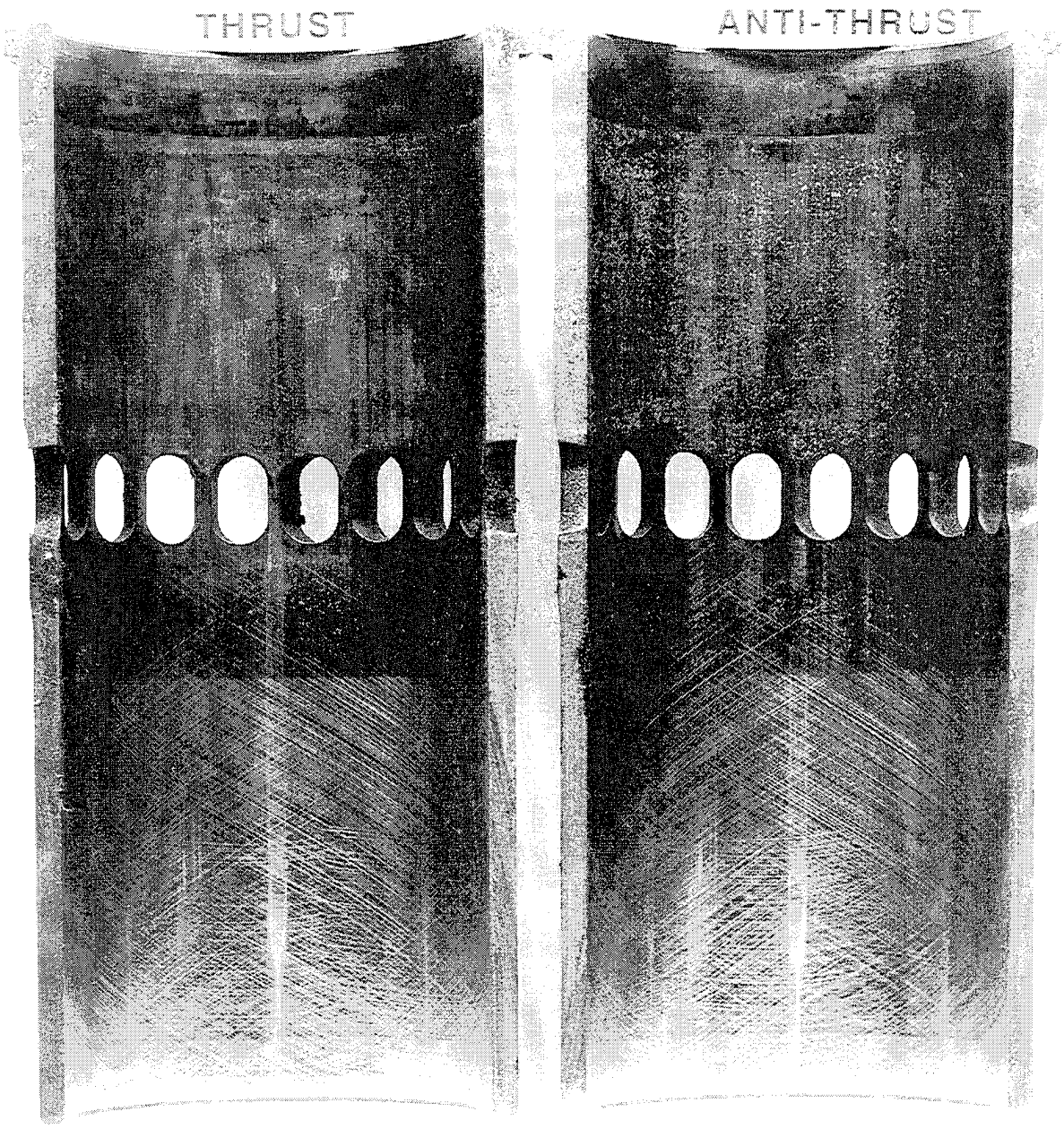
6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
3-L



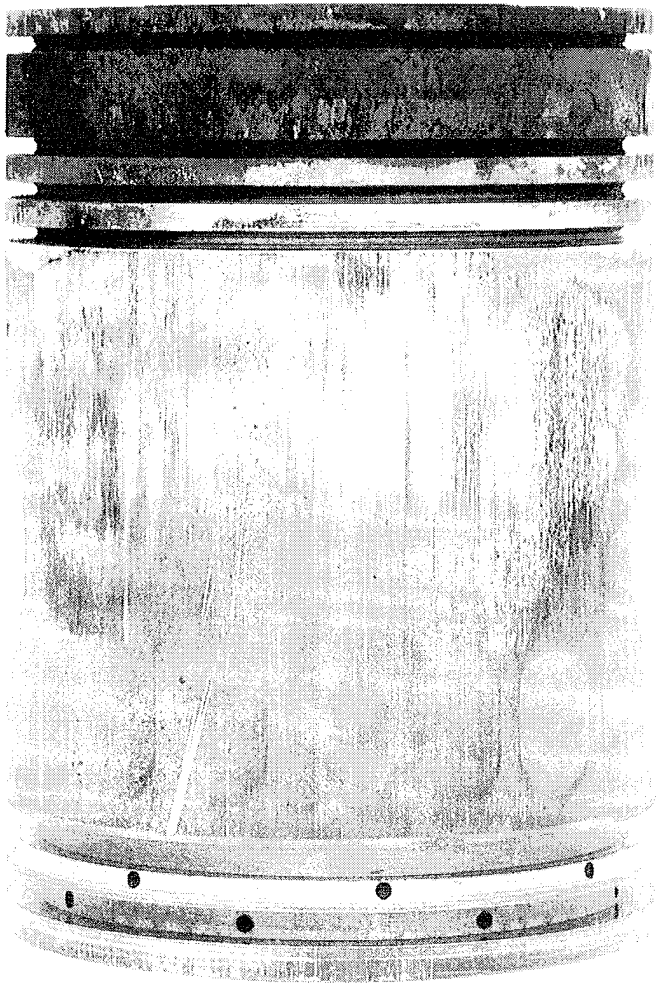
6V53T 56A
AL-19526-L REF DF-2
0-23 HRS.
2-R



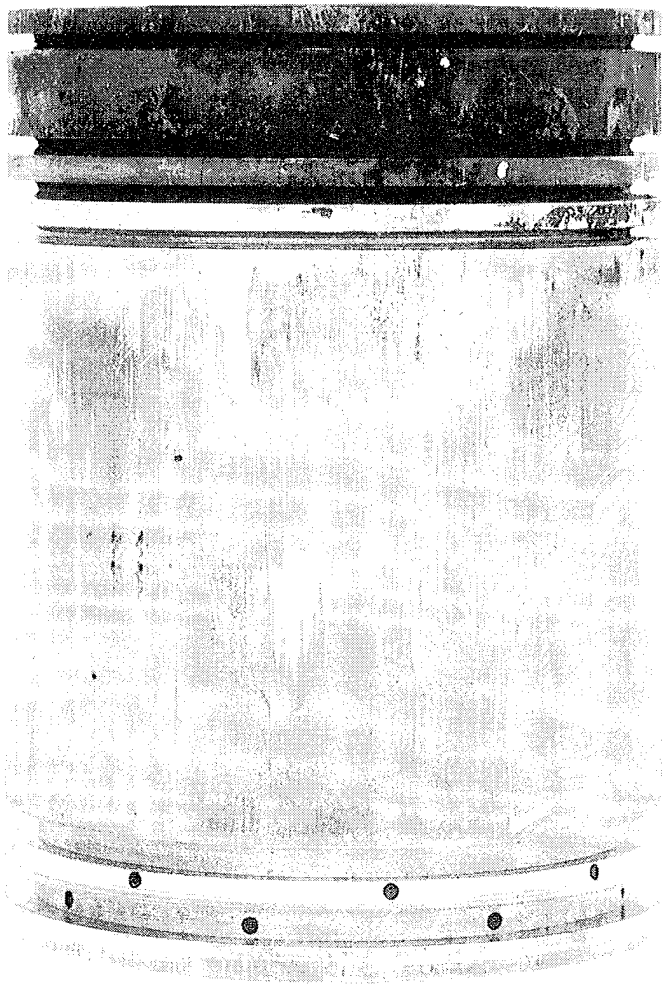
6V53T 56A
AL-19526-L REF DF-2
0-20 HRS.
3-R



6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
1-R-T

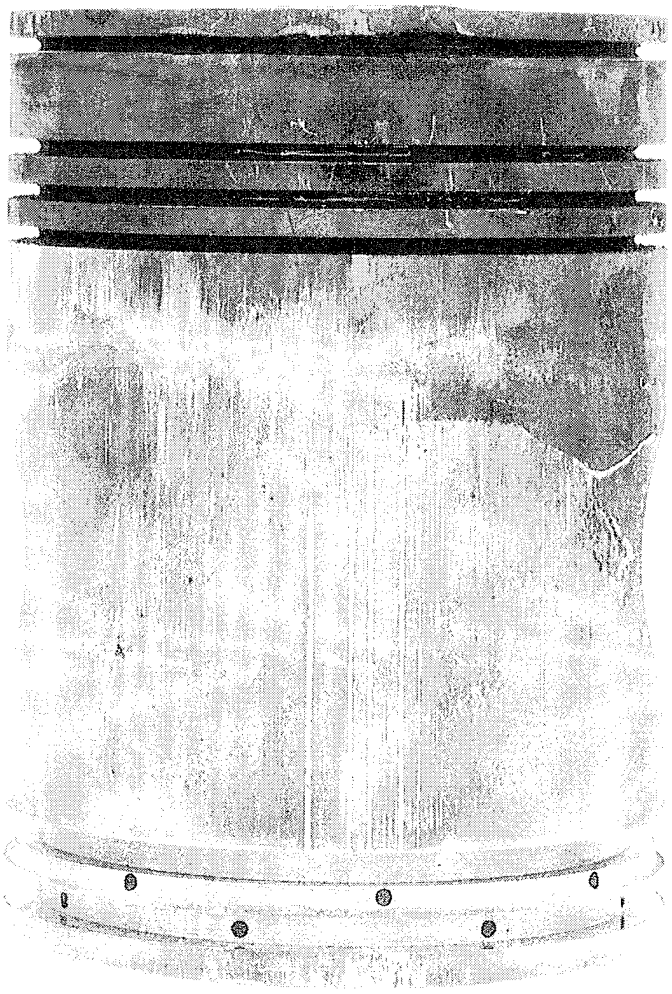


6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
1-R-AT

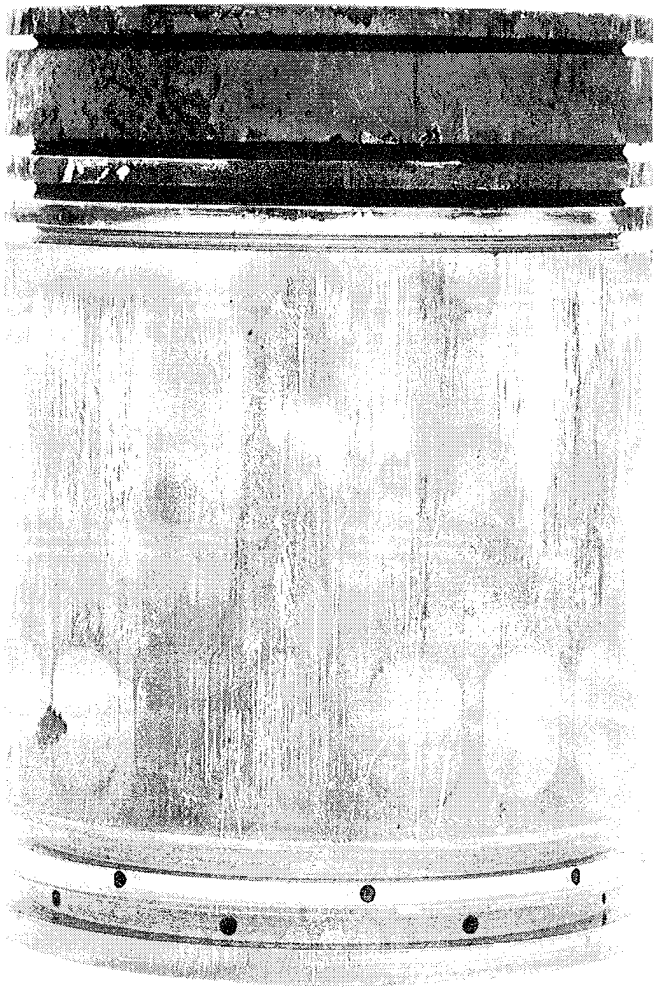


6V53T 56A
AL-19528-L REF DF-2
20-151.5 HRS.
2-R-T

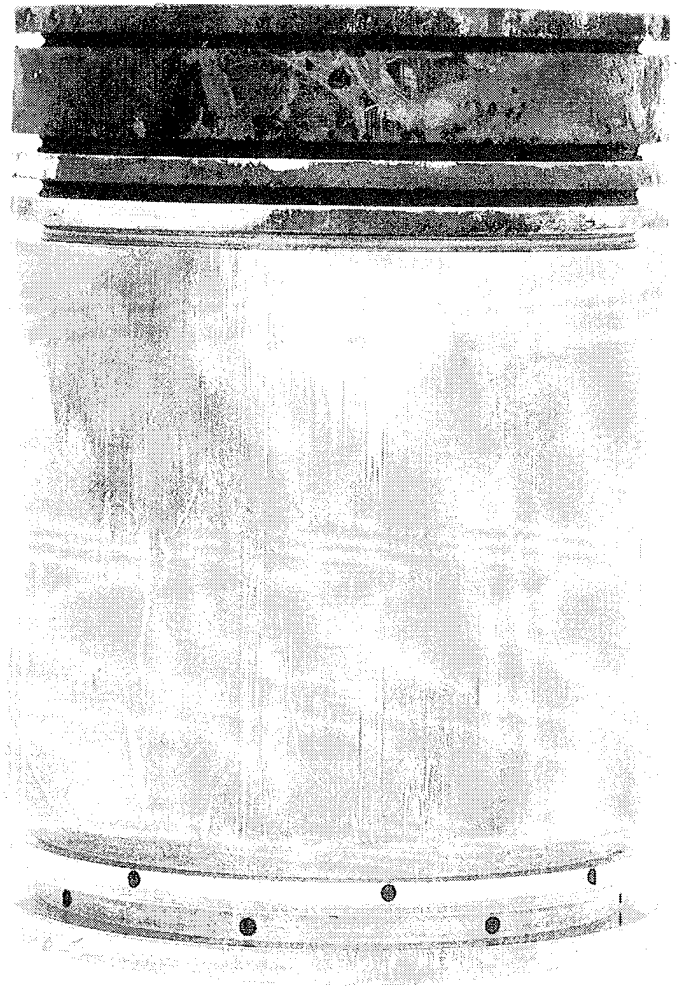
6V53T 56A
AL-19528-L REF DF-2
20-151.5 HRS.
2-R-AT



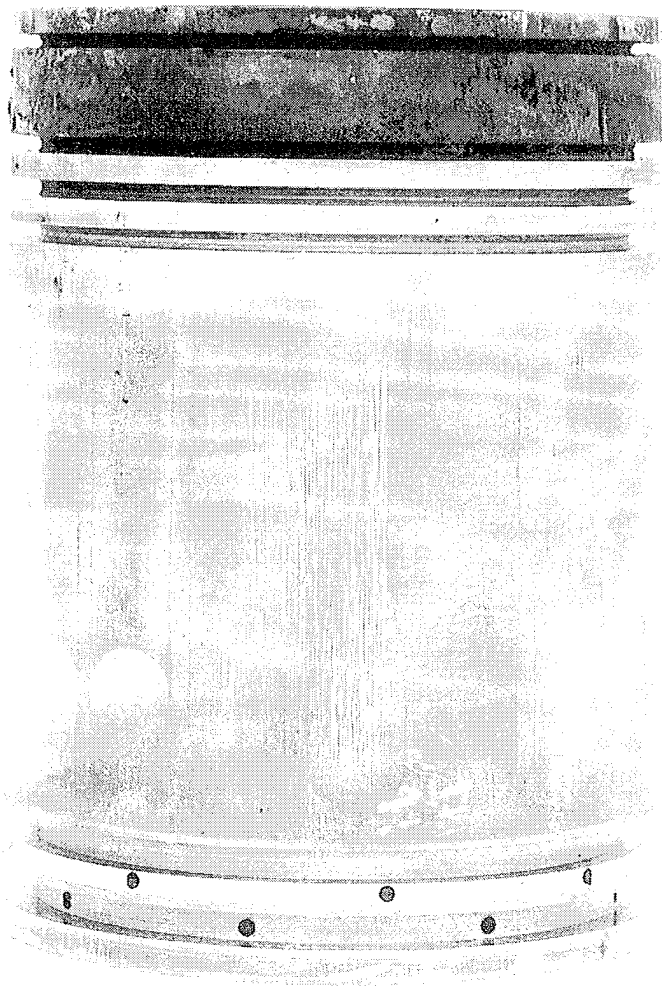
6V53T 56A
AL-19528-L REF DF-2
20-151.5 HRS.
3-R-T



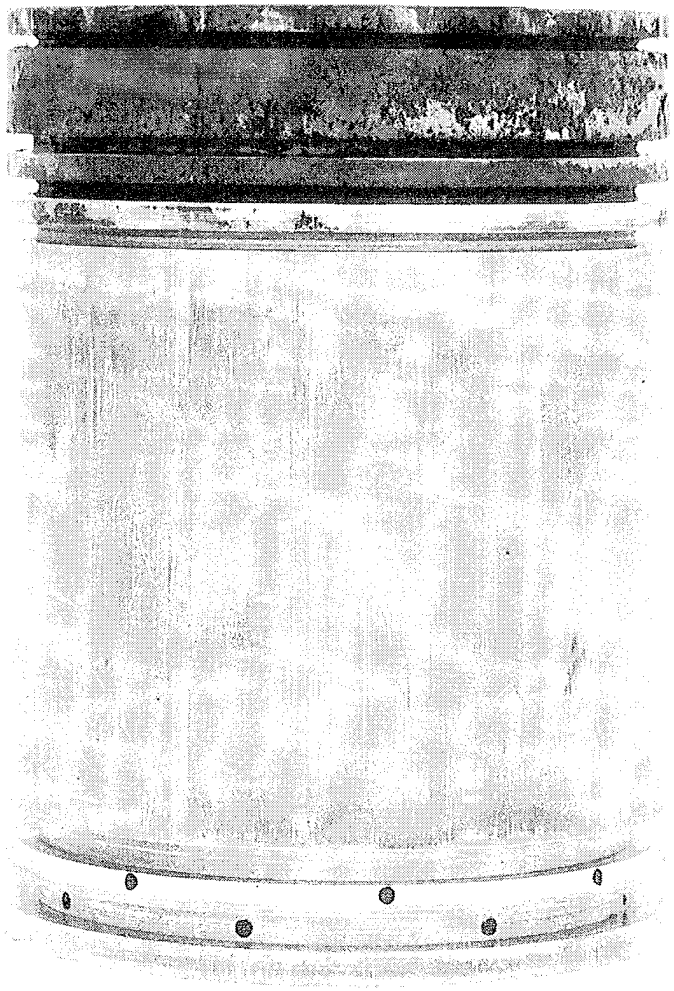
6V53T 56A
AL-19528-L REF DF-2
20-151.5 HRS.
3-R-AT



6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
1-L-T

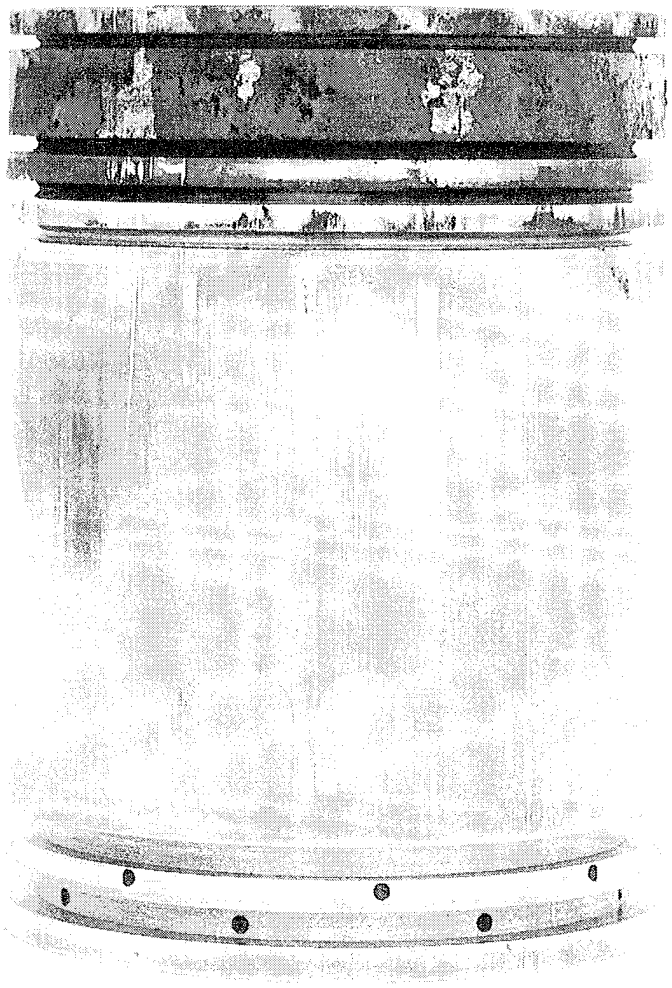


6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
1-L-AT

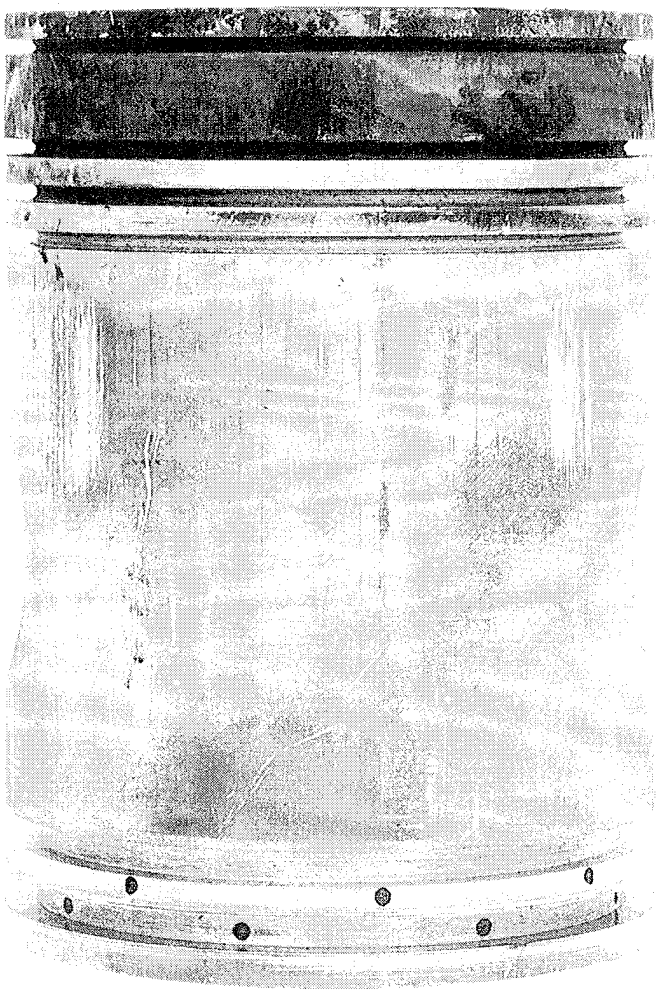


6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
3-L-T

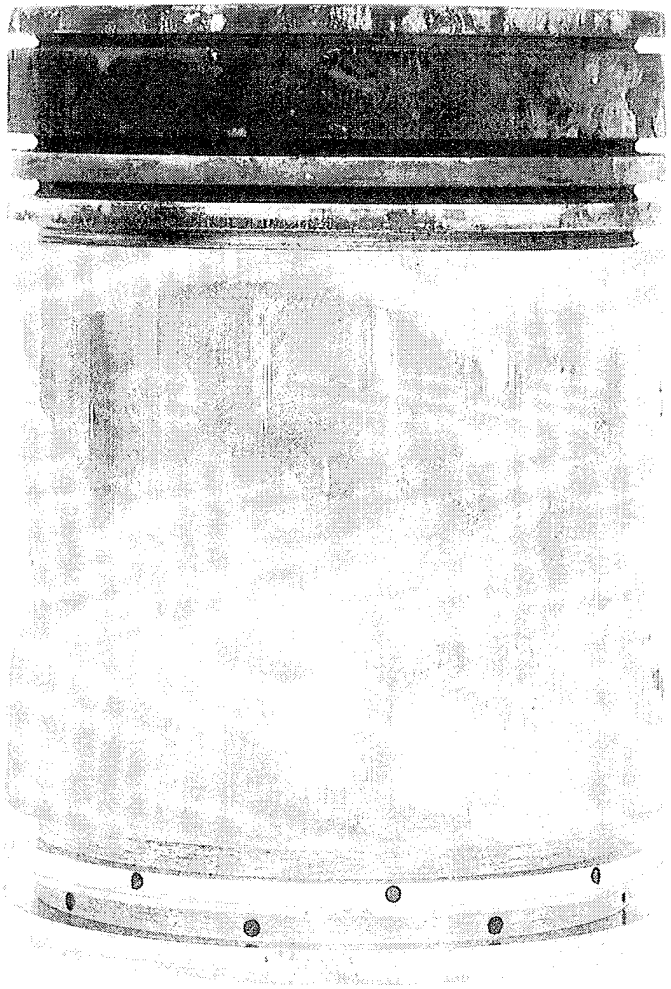
6V53T 56A
AL-19528-L REF DF-2
0-151.5 HRS.
3-L-AT



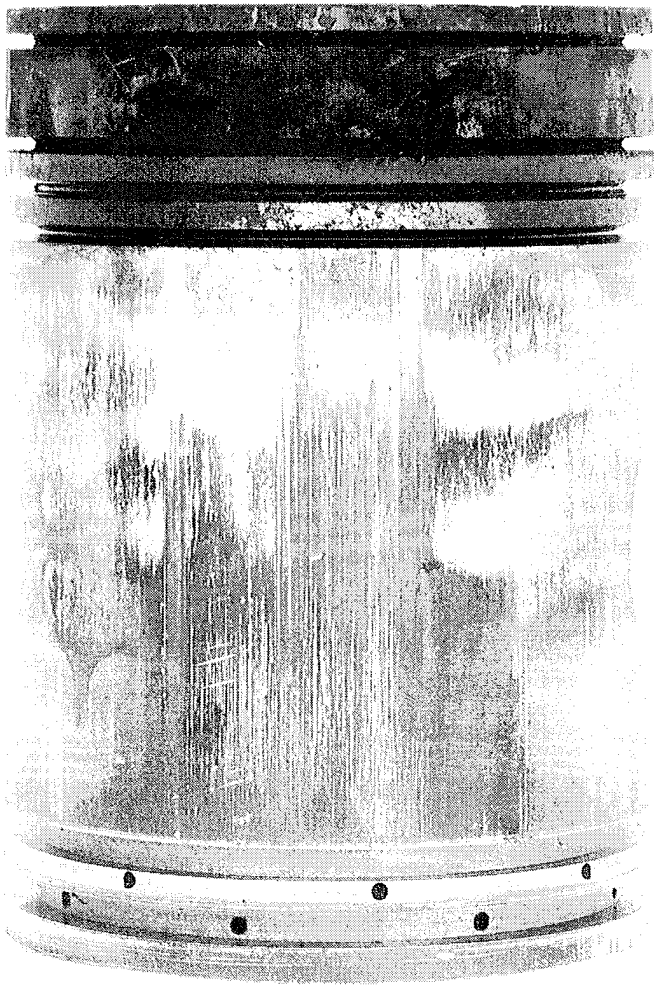
6V53T 56A
AL-19528-L REF DF-2
0-20 HRS.
2-R-T



6V53T 56A
AL-19528-L REF DF-2
0-20 HRS.
2-R-AT



6V53T 56A
AL-19528-L REF DF-2
0-20 HRS.
3-R-T



6V53T 56A
AL-19528-L REF DF-2
0-20 HRS.
3-R-AT

APPENDIX C

Test 6V-53T — 57A

Lubricant "A-1"
AL-19660-L

6V-53T
Test 57A
ENGINE REBUILD MEASUREMENTS
Lubricant: AL-19660-L

	Min		Max		Avg		Specified Limits		
	mm	in.	mm	in.	mm	in.	mm (in.)	-	mm (in.)
CYLINDER BLOCK BORE									
Inside Diameter (Bottom)	110.651	4.3565	110.676	4.3575	110.663	4.3570	110.655 (4.3565)	-	110.681 (4.3575) New
								-	110.731 (4.3595) Max
Out-of-Round	0.000	0.0000	0.015	0.0006	0.005	0.0002			
Taper	0.000	0.0000	0.015	0.0006	0.004	0.0002		-	0.038 (0.0015) Max
								-	0.038 (0.0015) Max
CYLINDER LINERS (Installed)									
Inside Diameter	98.434	3.8755	98.462	3.8766	98.446	3.8760	98.430 (3.8752)	-	98.468 (3.8767)
Out-of-Round	0.000	0.0000	0.013	0.0005	0.005	0.0002		-	0.038 (0.0015) Max
Taper	0.000	0.0000	0.015	0.0006	0.006	0.0002		-	0.038 (0.0015) Max
Piston Diameter (at Skirt)	98.248	3.8682	98.253	3.8684	98.251	3.8683	98.219 (3.8669)	-	98.775 (3.8691)
Piston Skirt-to-Cylinder Liner Clearance	0.180	0.0071	0.211	0.0083	0.194	0.0076	0.155 (0.0061)	-	0.249 (0.0098)
COMPRESSION RINGS									
Gap (No. 1, Fire Ring)	0.74	0.029	0.99	0.039	0.83	0.033	0.51 (0.020)	-	1.0 (0.040)
Gap (Nos. 2, 3, 4)	0.63	0.025	0.81	0.032	0.72	0.028	0.51 (0.020)	-	1.0 (0.040)
RING-TO-GROOVE CLEARANCE									
Top (No. 1, Fire Ring)	0.076	0.0030	0.102	0.0040	0.080	0.0032	0.08 (0.0030)	-	0.17 (0.0066)
No. 2, Compression Ring	0.178	0.0070	0.203	0.0080	0.190	0.0075	0.18 (0.0070)	-	0.27 (0.0105)
Nos. 3 and 4, Compression Rings	0.127	0.0050	0.152	0.0060	0.146	0.0058	0.13 (0.0050)	-	0.22 (0.0085)
OIL CONTROL RINGS (Nos. 5, 6, 7)									
Gap	0.279	0.0110	0.381	0.0150	0.339	0.0133	0.254 (0.0100)	-	0.508 (0.020)
Ring-to-Groove Clearance	0.076	0.0030	0.076	0.0030	0.076	0.0030	0.038 (0.0015)	-	0.140 (0.0055)
PISTON PIN									
Pin-to-Piston Bushing Clearance	0.071	0.0028	0.081	0.0032	0.075	0.0030	0.064 (0.0025)	-	0.864 (0.0034)
Pin-to-Connecting Rod Bushing Clearance	0.033	0.0013	0.041	0.0016	0.037	0.0015	0.025 (0.0010)	-	0.048 (0.0019)
Connecting Rod Bearing-to-Journal Clearance	0.033	0.0013	0.048	0.0019	0.043	0.0017	0.028 (0.0011)	-	0.104 (0.0041)
Main Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.076 (0.0030)	-	0.127 (0.0050)
Camshaft Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.114 (0.0045)	-	0.152 (0.0060)

Detroit Diesel 6V-53T
Test 57A
240-HR TRACKED VEHICLE CYCLE ENDURANCE TEST — OPERATING CONDITIONS SUMMARY
Lubricant: AL-19660-L
Fuel: Reference No. 2 Diesel Fuel

	Maximum Power Mode, 2,800 rpm		Maximum Torque Mode, 2,200 rpm	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	2,801	1	2,201	1
Torque, N-m (lb-ft)	757 (553)	4.1 (3)	852 (622)	0.9 (2)
Fuel Consumption, kg/hr (lb/hr)	53.9 (119)	0.4 (1)	46.7 (103)	0.4 (1)
Observed Power, kW (bhp)	220 (295)	1 (2)	194 (261)	1 (1)
BSFC, g/kW-hr (lb/bhp-hr)	0.245 (0.404)	0.0014 (0.0023)	0.240 (0.396)	0.0018 (0.0029)
Temperatures, °C (°F)				
Exhaust Before Turbo	413 (775)	56 (101)	402 (755)	55 (99)
Exhaust After Turbo	410 (770)	4 (8)	424 (794)	5 (9)
Water Jacket Inlet	72 (162)	1 (1)	72 (161)	1 (1)
Water Jacket Outlet	77 (171)	1 (1)	77 (171)	1 (1)
Oil Sump	111 (233)	6 (11)	106 (223)	1 (2)
Fuel at Filter	35 (96)	2 (3)	34 (94)	1 (2)
Inlet Air	33 (91)	2 (3)	32 (90)	2 (3)
Airbox	140 (284)	3 (6)	111 (231)	2 (3)
Air After Compressor	128 (263)	3 (5)	106 (223)	2 (4)
Blowby	58 (137)	2 (4)	49 (120)	2 (4)
Oil Gallery	100 (212)	1 (2)	94 (201)	1 (1)
Wet Bulb Temperature	30 (85)	6 (10)	30 (86)	4 (7)
Dry Bulb Temperature	35 (95)	4 (7)	35 (95)	4 (7)
Pressures				
Exhaust Before Turbo, kPa (psi)	94.6 (13.7)	1.2 (0.18)	63.3 (9.2)	0.7 (0.11)
Compressor Discharge, kPa (psi)	95.5 (13.8)	1.5 (0.22)	71.9 (10.4)	1.0 (0.15)
Blower Discharge, kPa (psi)	119.4 (17.3)	2.2 (0.33)	73.0 (10.6)	1.4 (0.20)
Fuel Transfer Pump, kPa (psi)	482.2 (69.9)	1.9 (0.28)	460.2 (66.7)	3.6 (0.53)
Oil Gallery, kPa (psi)	275.0 (39.9)	11.3 (1.64)	250.7 (36.3)	5.2 (0.76)
Intake Vacuum, kPa (in. Hg)	29.3 (8.65)	0.9 (0.27)	18.1 (5.34)	0.6 (0.18)
Barometric Pressure, kPa (in. Hg)	97.9 (28.90)	0.3 (0.08)	97.9 (28.92)	0.3 (0.10)
Exhaust Common, kPa (in. H_2O)	5.9 (23.61)	0.2 (0.80)	4.1 (16.64)	0.2 (0.63)
Blowby, kPa (in. H_2O)	0.4 (1.46)	0.3 (1.29)	0.1 (0.38)	0.0 (0.08)

6V-53T
Test 57A
LUBRICANT ANALYSIS
Lubricant: AL-19660-L

Lubricant Analysis	ASTM Test Method	Test Time, hr 0	120	240
Kinematic Viscosity, cSt, at				
40°C	D 445	53.20	51.85	51.66
100°C	D 445	9.99	9.56	9.63
Total Acid Number, mg KOH/g	D 664	2.19	2.56	3.28
Total Base Number, mg KOH/g	D 664	5.99	2.71	3.18
Pentane B Insolubles, wt%	D 893	ND*	0.02	0.02
Toluene B Insolubles, wt%	D 893	ND	0.02	0.02
Flash Point, °C	D 92	238	227	227

* ND = Not Determined

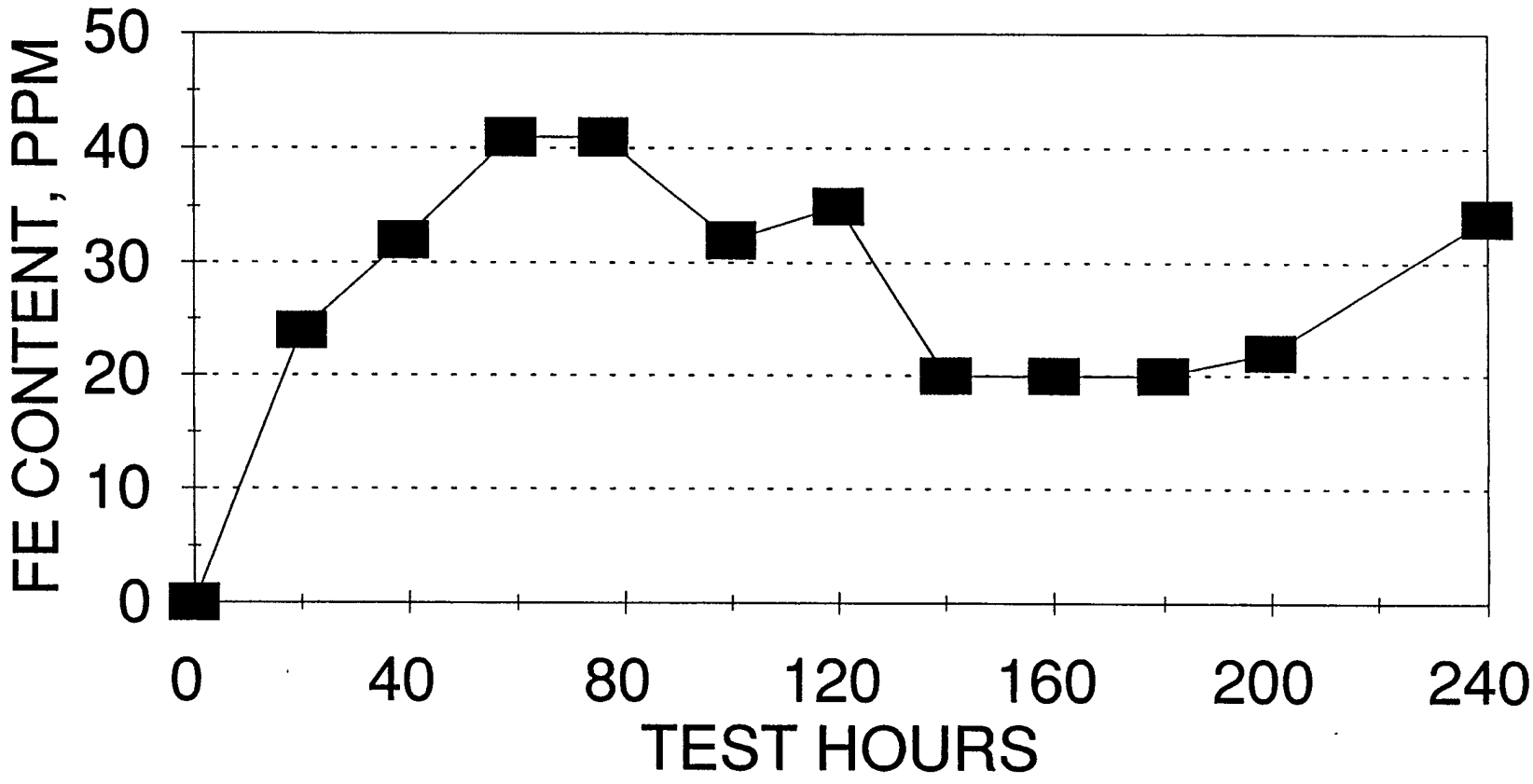
6V-53T
Test 57A
TOTAL OIL CONSUMPTION AND WEAR METALS BY XRF
Lubricant: AL-19660-L

Test Time, hr	Total Oil Consumed kg	lb	Wear Metals, ppm Fe	Cu
0	--	--	<20	<20
20	6.38	14.07	24	<20
39	11.19	24.66	32	<20
59	19.19	42.30	41	<20
76.5	25.42	56.04	41	<20
100	31.53	69.50	32	<20
120	39.99	88.17	35	<20
140	47.56	104.84	<20	<20
160	56.12	123.72	<20	<20
180	65.81	145.08	<20	<20
200	77.99	171.93	22	<20
223	96.68	213.15	ND*	ND
240	111.50	245.82	34	<20
	kg/hr	lb/hr		
Average Oil Consumption Rate	0.4646	1.024		

* ND = Not Determined

USED OIL IRON CONTENT

6V53T TEST #57A AL-19660



6V-53T
Test 57A
POST-TEST ENGINE CONDITIONS AND DEPOSITS
Lubricant: AL-19660-L

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Avg
CYLINDER LINER							
Intake Port Plugging							
% Restriction	<1	<1	<1	<1	<1	<1	<1
Liner Scuffing, % Area							
Thrust	18	60	2	38	28	94	40.00
Antithrust	0	39	0	21	49	58	27.83
% Total Area	9.0	49.5	1.0	29.5	38.5	76.0	33.92
						Overall:	33.92
					Overall, Five Cylinders (w/o 3R):		25.50
% Area Bore Polished							
Thrust	7	5	11	5	3	2	5.50
Antithrust	9	7	15	12	14	8	10.83
% Avg Area Bore Polished	8.0	6.0	13.0	8.5	8.5	5.0	8.17
						Overall:	8.17
					Overall, Five Cylinders (w/o 3R):		8.80
Avg Liner Distress	10	51.5	1	31.5	38.5	76	34.7
					Overall, Five Cylinders (w/o 3R):		26.5
RINGS							
Ring Face Distress, Six Cylinders, Demerits							
No. 1	9.75	50.00	1.25	8.00	4.75	56.25	21.67
No. 2	29.50	48.75	1.50	36.25	12.75	73.75	33.75
No. 3	42.50	51.25	3.25	25.50	9.50	73.75	34.29
No. 4	35.00	43.75	4.75	38.75	16.50	73.75	35.42
						Overall:	31.28
					Overall, Five Cylinders (w/o 3R):		23.66
PISTONS							
Piston Skirt Rating*							
Thrust	8% SC & S	35% SC & Lt S	15% SC & Lt S	30% SC & Lt S	35% SC & Lt S	80% SC & Lt S	
Antithrust	Lt S	5% SC & Lt S	Lt S	Lt S	Lt S	3% SC & Lt S	
Piston WTD Rating**							
Six Cylinders	265.00	238.62	245.88	281.51	320.13	257.76	268.15
Five Cylinders	265.00	238.62	245.88	281.51	320.13	--	270.23
Ring Sticking***							
No. 1	F	F, PC	F	F	F	F, PC	
No. 2	F	F	F	F	F	F, PC	
No. 3	F	F	F	F	F	F	
No. 4	F	F	F	F	F	F	
EXHAUST VALVES							
Deposits							
Head+	20 HC, 35 MC 15 LC	50 HC, 35 MC 15 LC	10 HC, 60 MC 40 LC	25 HC, 35 MC 40 LC	20 HC, 70 MC 10 LC	25 HC, 10 MC 65 LC	
Face	← Light Amount of Carbon and Ash Embedment →						
Tulip++	1.0	1.0	1.0	1.0	1.0	1.0	
Stem	← All Stems 5 to 15% #9 Lacquer →						
Surface Conditions							
Freeness in Guide	← All Normal →						
Head	← All Normal →						
Face	← All Normal →						
Seat	← All Normal →						
Stem	← All Normal →						
Tip	← All Normal →						

* Lt = Light, S = Scratches, PM = Plating Melted, N = Normal, SC = Scuffing, and B = Burn

** CRC Weighted Total Deposits (0 = Least, 900 = Most)

*** F = Free, PC = Partially Collapsed, TC = Totally Collapsed, BR = Broken, and CS = Cold Stuck

\+ HC = Hard Carbon, LC = Light Carbon, MC = Medium Carbon — the number indicates percentage

++ The higher the number, the darker the lacquer (0 = Lightest, 9 = Darkest)

6V-53T
Test 57A
LINER AND RING FACE DISTRESS SUMMARY
Lubricant: AL-19660-L

Liner Distress

Six-Cylinder Avg	34.7
Five-Cylinder Avg (w/o 3R)	26.5

Ring Face Distress, Nos. 2 and 3

Six-Cylinder Avg	34.02
Five-Cylinder Avg (w/o 3R)	26.08

6V-53T
Test 57A
WEAR MEASUREMENTS
Lubricant: AL-19660-L

Cylinder Liner Bore Diameter Changes

	Cylinder Number											
	1L				2L				3L			
	T-AT*		F-B		T-AT		F-B		T-AT		F-B	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Top	0.036	0.0014	0.000	0.0000	0.048	0.0019	–0.005	–0.0002	0.030	0.0012	–0.005	–0.0002
Middle	–2.641	–0.1040	0.015	0.0006	0.028	0.0011	0.008	0.0003	0.015	0.0006	0.010	0.0004
Bottom	0.000	0.0000	0.005	0.0002	0.013	0.0005	0.010	0.0004	0.005	0.0002	0.010	0.0004

	Cylinder Number											
	1R				2R				3R			
	T-AT		F-B		T-AT		F-B		T-AT		F-B	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Top	0.071	0.0028	–0.003	–0.0001	0.041	0.0016	0.046	0.0018	0.056	0.0022	–0.008	–0.0003
Middle	0.020	0.0008	0.010	0.0004	0.025	0.0010	0.015	0.0006	0.020	0.0008	0.041	0.0016
Bottom	0.015	0.0006	0.015	0.0006	0.005	0.0002	0.010	0.0004	0.000	0.0000	0.000	0.0000

Average Change

	T-AT		F-B	
	mm	in.	mm	in.
Top	0.047	0.0018	0.004	0.0002
Middle	–0.422	–0.0166	0.017	0.0006
Bottom	0.006	0.0003	0.008	0.0003

Piston Ring End Gap Change

	Cylinder Number													
	1L		2L		3L		1R		2R		3R		Average Change	
Ring No.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
1	0.000	0.0000	0.203	0.0080	–0.051	–0.0020	0.051	0.0020	0.051	0.0020	0.076	0.0030	0.030	0.0012
2	–0.025	–0.0010	0.025	0.0010	0.000	0.0000	0.025	0.0010	0.025	0.0010	0.102	0.0040	0.025	0.0010
3	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.025	0.0010	0.000	0.0000	0.025	0.0010	0.026	0.0010
4	–0.025	–0.0010	0.000	0.0000	0.000	0.0000	0.025	0.0010	0.000	0.0000	0.000	0.0000	0.074	0.0029
5	0.076	0.0030	0.127	0.0050	0.152	0.0060	0.152	0.0060	0.152	0.0060	0.152	0.0060	0.112	0.0044
6	0.102	0.0040	0.102	0.0040	0.127	0.0050	0.152	0.0060	0.127	0.0050	0.127	0.0050	0.068	0.0027
7	0.076	0.0030	0.076	0.0030	0.127	0.0050	0.127	0.0050	0.127	0.0050	0.127	0.0050	0.063	0.0025

Overall Average Change

mm	in.
0.057	0.0022

* T-AT = Thrust-Antithrust, F-B = Front-Back

6V-53T
Test 57A
WEAR MEASUREMENTS (CONT'D)
Lubricant: AL-19660-L

Average Piston Radial Width Change

	Cylinder Number													
	1L		2L		3L		1R		2R		3R		Average Change	
Ring No.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
1	–0.039	–0.0015	–0.045	–0.0018	–0.030	–0.0012	–0.034	–0.0013	–0.019	–0.0008	–0.047	–0.0019	–0.036	–0.0014
2	–0.024	–0.0010	–0.029	–0.0011	–0.029	–0.0012	–0.017	–0.0007	–0.034	–0.0013	–0.049	–0.0019	–0.030	–0.0012
3	0.029	0.0012	0.004	0.0002	–0.013	–0.0005	–0.008	–0.0003	–0.010	–0.0004	–0.025	–0.0010	–0.004	–0.0001
4	–0.029	–0.0011	–0.034	–0.0013	–0.027	–0.0011	–0.032	–0.0013	0.048	0.0019	–0.029	–0.0011	–0.017	–0.0007

Overall Average Change

mm	in.
–0.022	–0.0009

6V-53T RING FACE DISTRESS
(Six Cylinders)

Sponsor Code: AL-19660-L
Hours: 240

Date: 06-06-91

SwRI Code: BFLRF
Block: 01 Test 57A

Cylinder No.	Ring No.	Extreme (1.00)		Heavy (0.75)		Medium (0.50)		Light (0.25)		Totals	
		% Area	Demerits	% Area	Demerits	% Area	Demerits	% Area	Demerits	% Area	Demerits
1L	1	0	0.00	10	7.50	2	1.00	5	1.25	17	9.75
	2	0	0.00	14	10.50	8	4.00	60	15.00	82	29.50
	3	0	0.00	30	22.50	10	5.00	60	15.00	100	42.50
	4	0	0.00	20	15.00	10	5.00	60	15.00	90	35.00
2L	1	0	0.00	55	41.25	5	2.50	25	6.25	85	50.00
	2	0	0.00	60	45.00	5	2.50	5	1.25	70	48.75
	3	0	0.00	40	30.00	25	12.50	35	8.75	100	51.25
	4	0	0.00	25	18.75	25	12.50	50	12.50	100	43.75
3L	1	0	0.00	1	0.75	0	0.00	2	0.50	3	1.25
	2	0	0.00	0	0.00	0	0.00	6	1.50	6	1.50
	3	0	0.00	0	0.00	1	0.50	11	2.75	12	3.25
	4	0	0.00	0	0.00	0	0.00	19	4.75	19	4.75
1R	1	0	0.00	5	3.75	4	2.00	9	2.25	18	8.00
	2	0	0.00	40	30.00	5	2.50	15	3.75	60	36.25
	3	0	0.00	20	15.00	15	7.50	12	3.00	47	25.50
	4	0	0.00	30	22.50	25	12.50	15	3.75	70	38.75
2R	1	0	0.00	1	0.75	3	1.50	10	2.50	14	4.75
	2	0	0.00	2	1.50	5	2.50	35	8.75	42	12.75
	3	0	0.00	1	0.75	5	2.50	25	6.25	31	9.50
	4	0	0.00	0	0.00	3	1.50	60	15.00	63	16.50
3R	1	0	0.00	60	45.00	5	2.50	35	8.75	100	56.25
	2	0	0.00	95	71.25	5	2.50	0	0.00	100	73.75
	3	0	0.00	95	71.25	5	2.50	0	0.00	100	73.75
	4	0	0.00	95	71.25	5	2.50	0	0.00	100	73.75

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	237	130.00	39.50	21.67
2	360	202.50	60.00	33.75
3	390	205.75	65.00	34.29
4	442	212.50	73.67	35.42
2 & 3	750	408.25	62.50	34.02

6V-53T RING FACE DISTRESS
(Five Cylinders)

Sponsor Code: AL-19960-L
Hours: 240

Date: 06-06-91

SwRI Code: BFLRF
Block: 01 Test 57A

Cylinder 3R Eliminated

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	137	73.75	27.40	14.75
2	260	128.75	52.00	25.75
3	290	132.00	58.00	26.40
4	342	138.75	68.40	27.75
2 & 3	550	260.75	55.00	26.08

6V-53T
PISTON DEMERIT SUMMARY

Sponsor Code: AL-19960-L
Hours: 240

Date: 06-06-91

SwRI Code: BFLRF
Block: 01 Test 57A

	Piston 1L	Piston 2L	Piston 3L	Piston 1R	Piston 2R	Piston 3R
Carbon (Grooves)	98.75	121.25	113.75	145.00	162.50	108.75
Carbon (Lands)	151.25	101.25	116.25	125.00	143.75	138.75
Lacquer (Grooves)	8.50	6.75	9.00	4.63	5.75	5.00
Lacquer (Lands)	6.50	9.37	6.88	6.88	8.13	5.26
Total Demerits	265.00	238.62	245.88	281.51	320.13	257.76

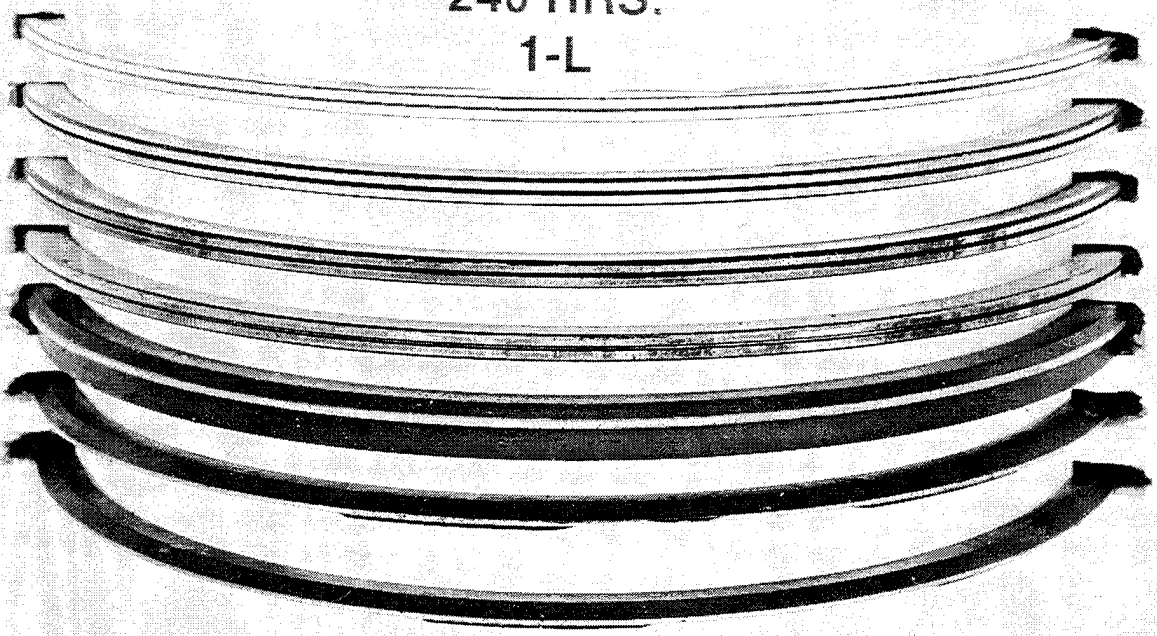
Average of All Six Pistons

Demerits Due to Carbon	1,526.3
Demerits Due to Lacquer	82.65
Total Demerits	1,608.9
Average Demerits	268.15
Average Piston	1L
Worst Piston	2R

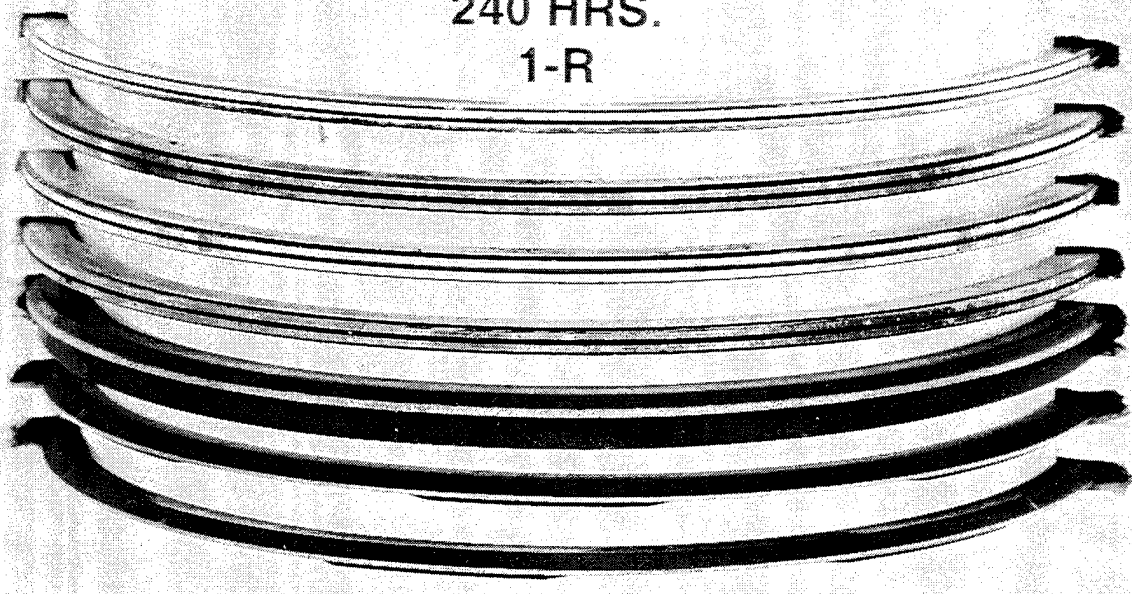
Average of Five Pistons Excluding 3R

Demerits Due to Carbon	1,278.8
Demerits Due to Lacquer	72.39
Total Demerits	1,351.1
Average Demerits	270.23
Average Piston	1L
Worst Piston	2R

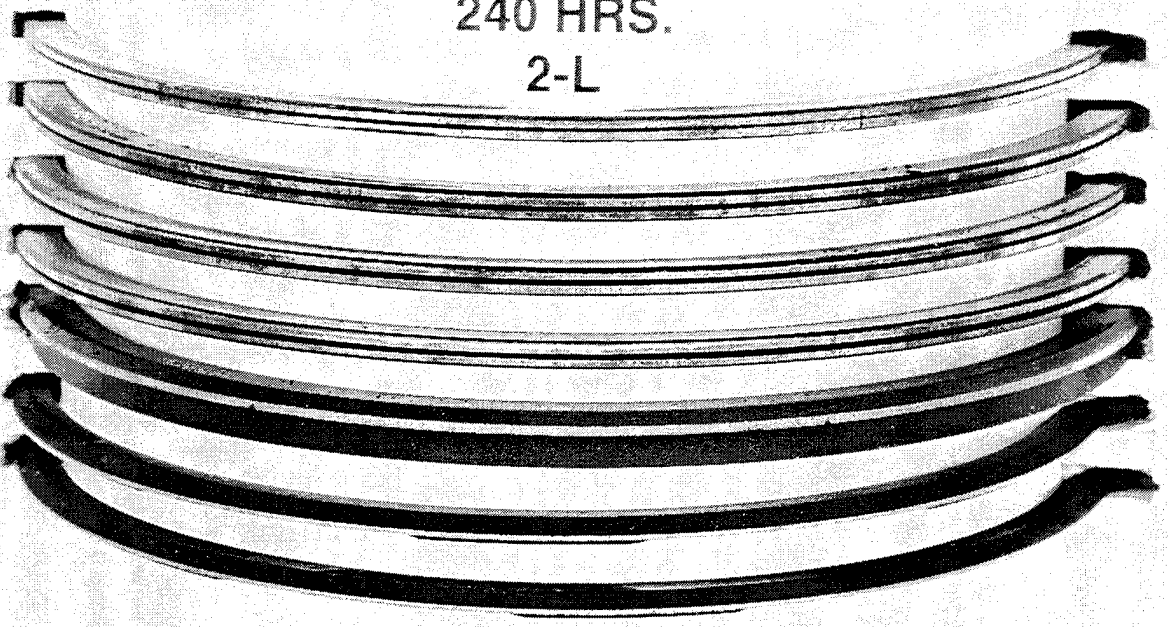
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
1-L



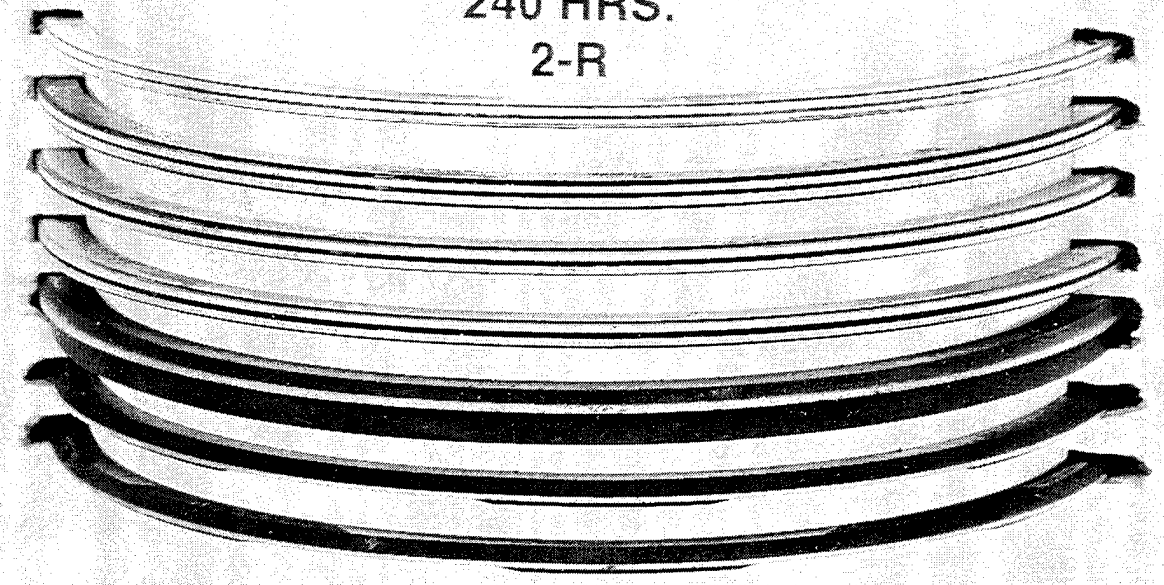
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
1-R



6V53T 57A
AL-19660-L REF DF-2
240 HRS.
2-L

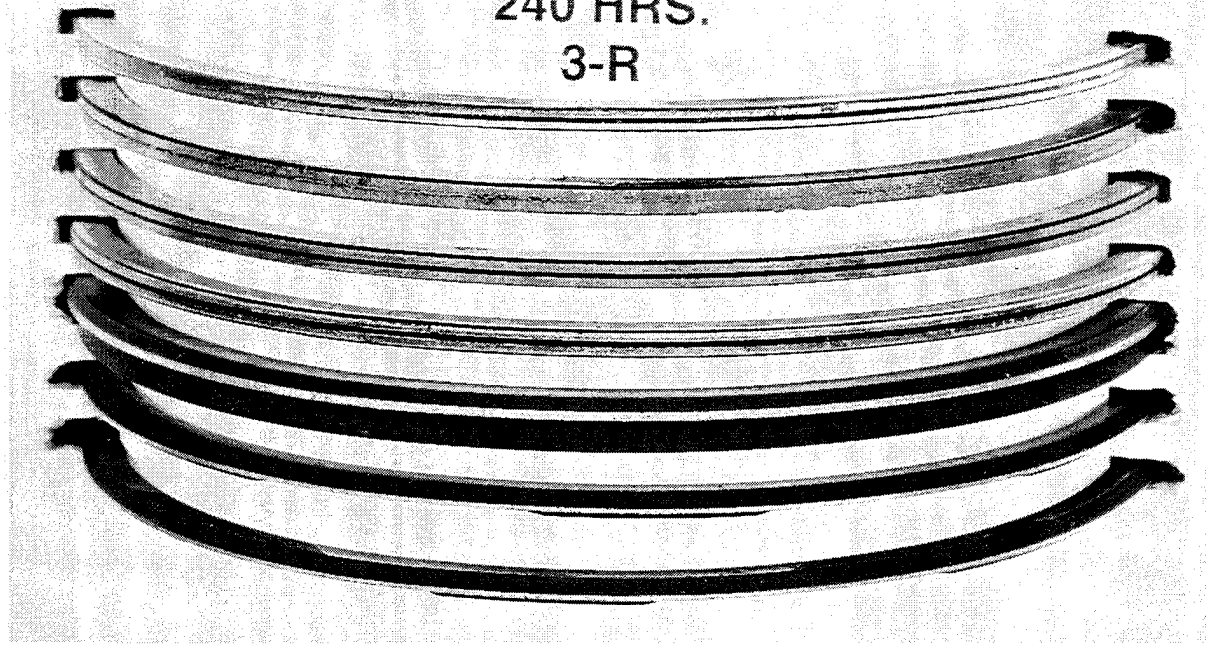


6V53T 57A
AL-19660-L REF DF-2
240 HRS.
2-R

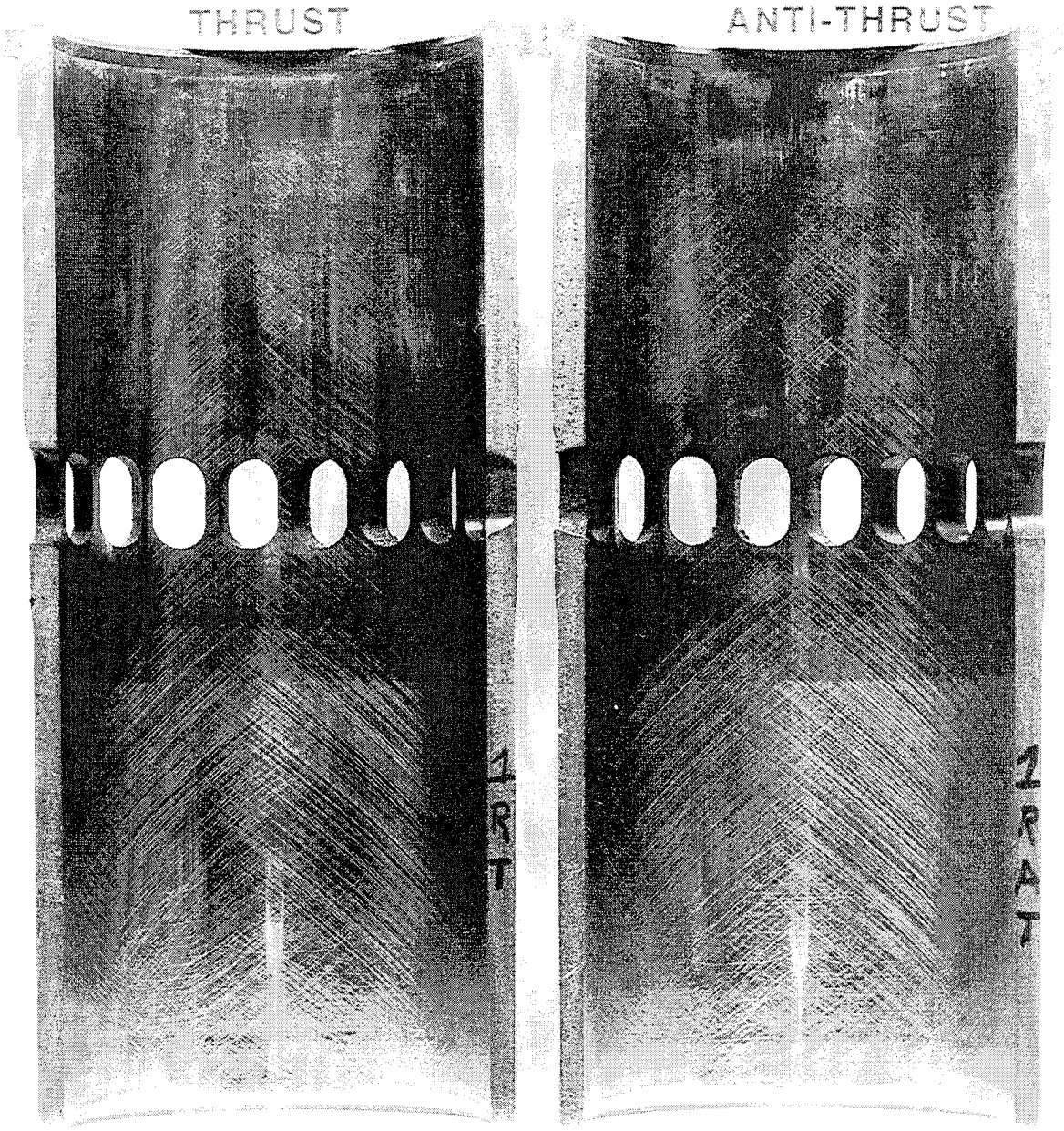


6V53T 57A
AL-19660-L REF DF-2
240 HRS.
3-L

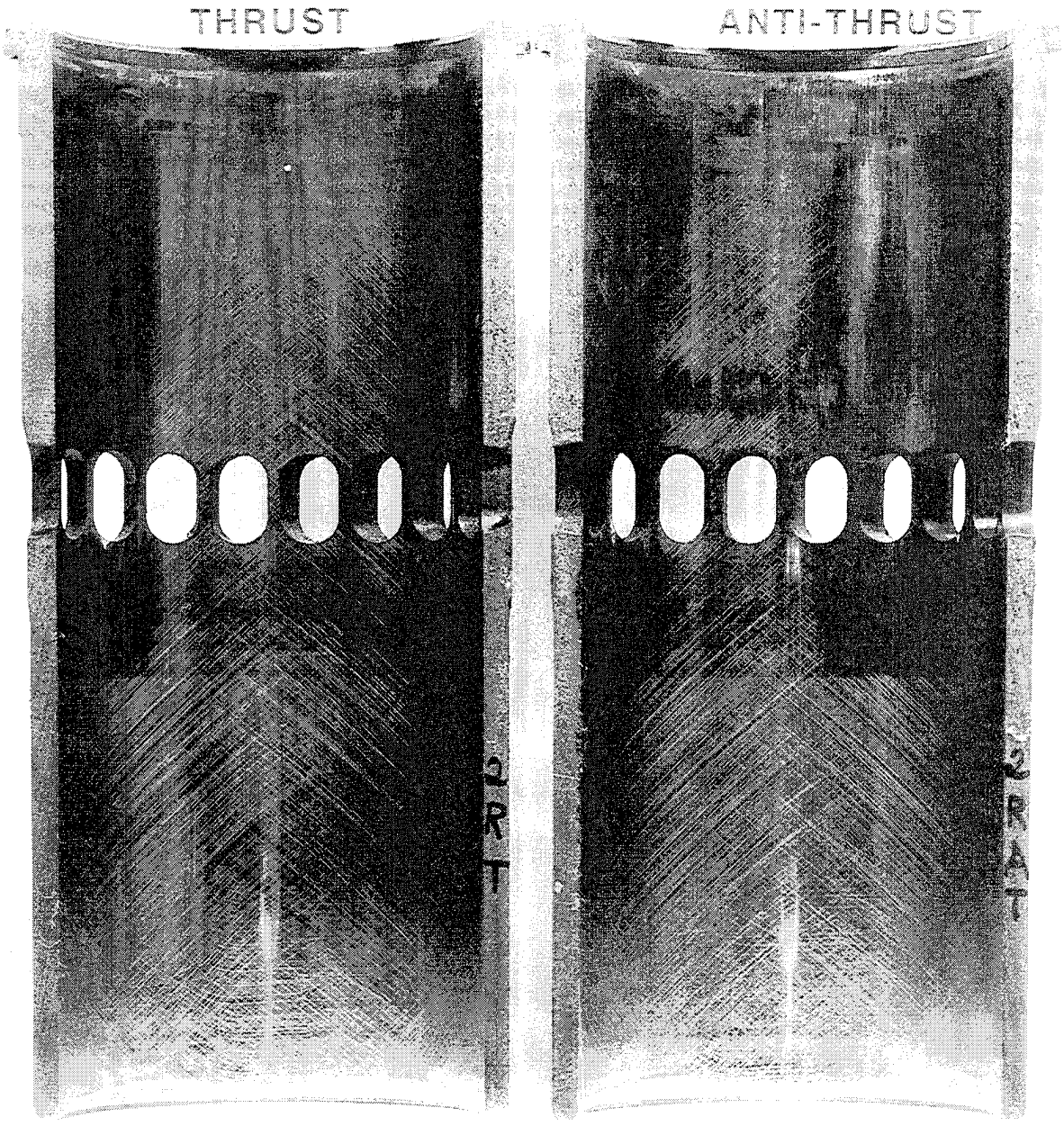
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
3-R



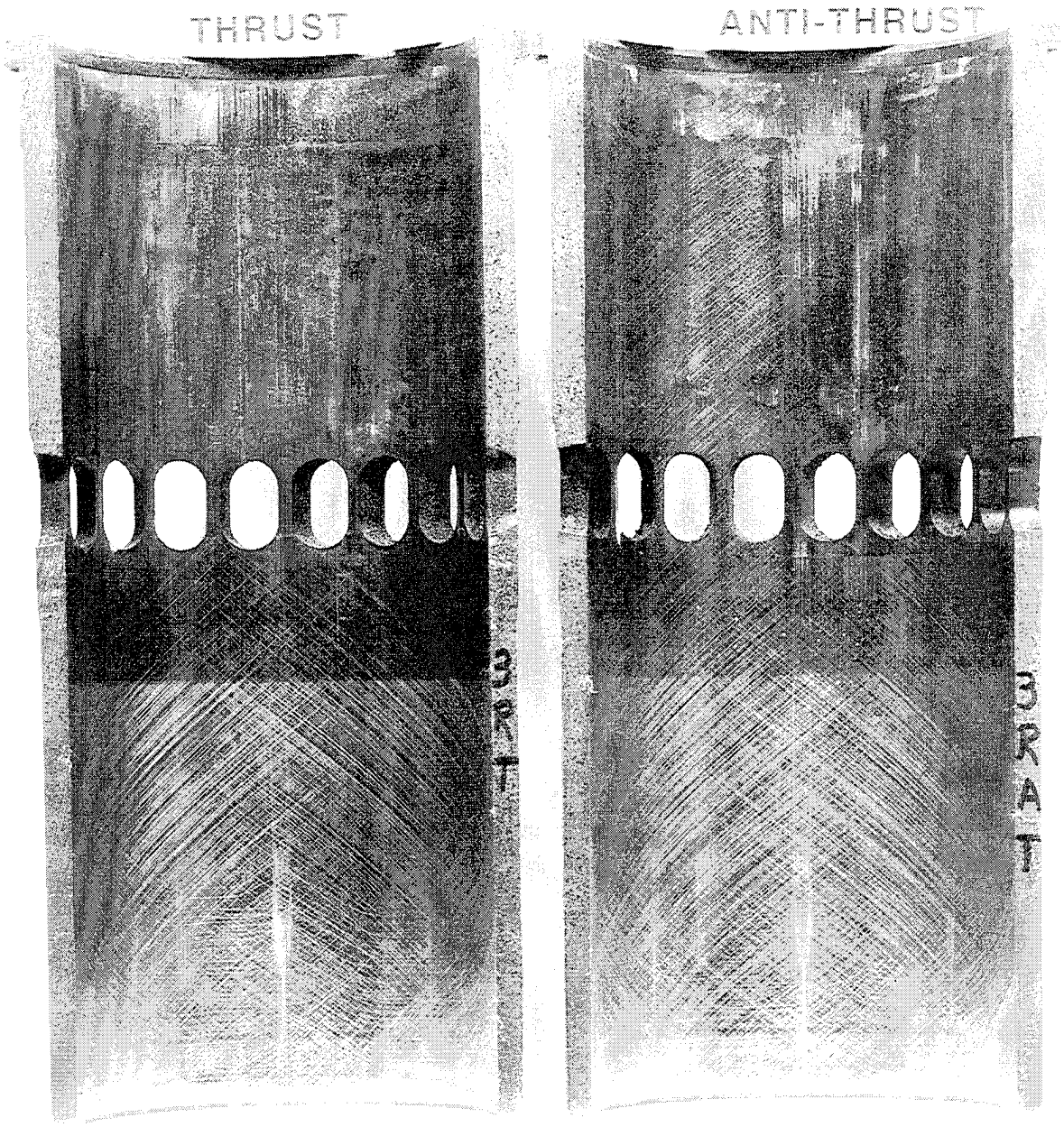
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
1-R



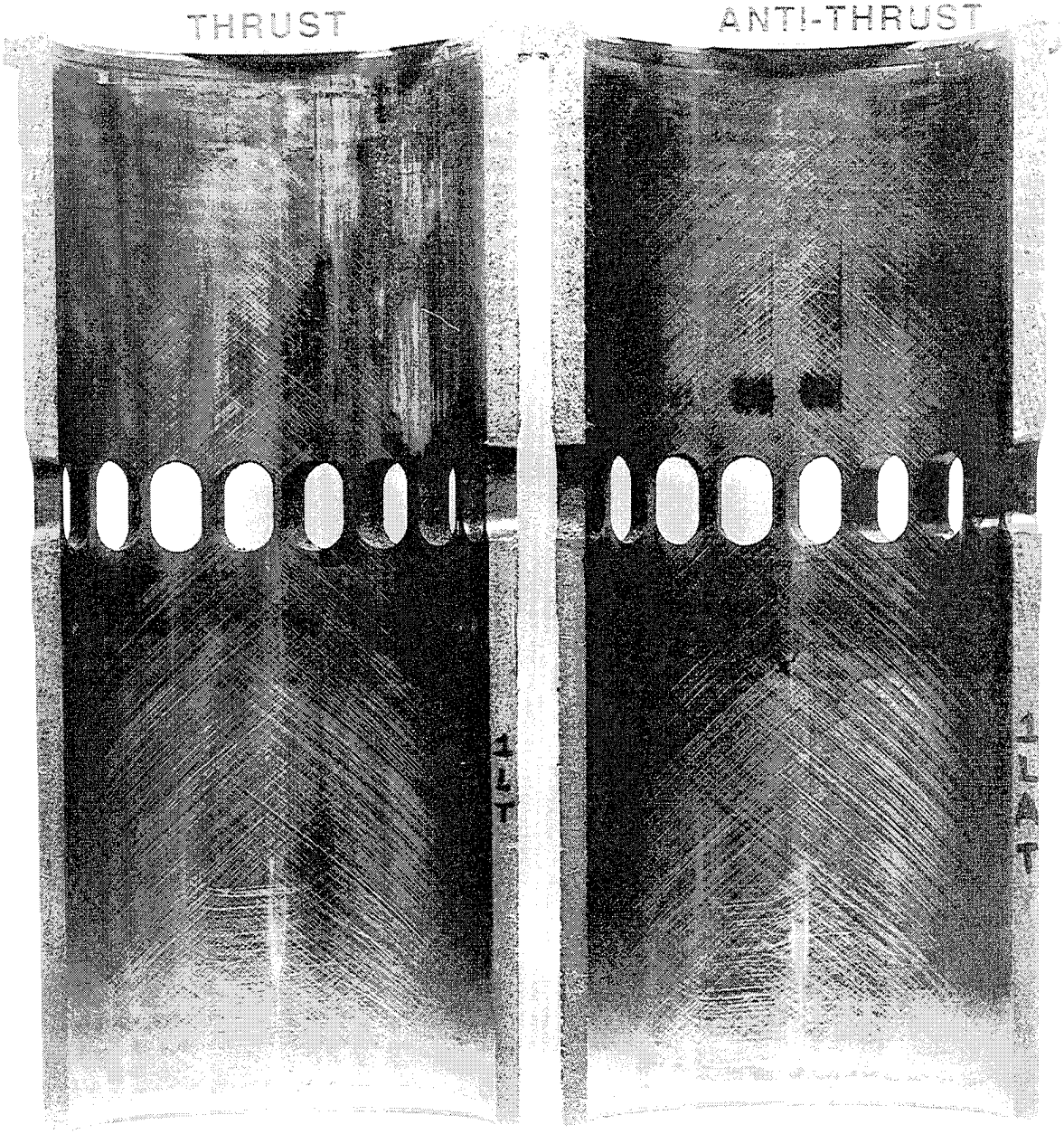
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
2-R



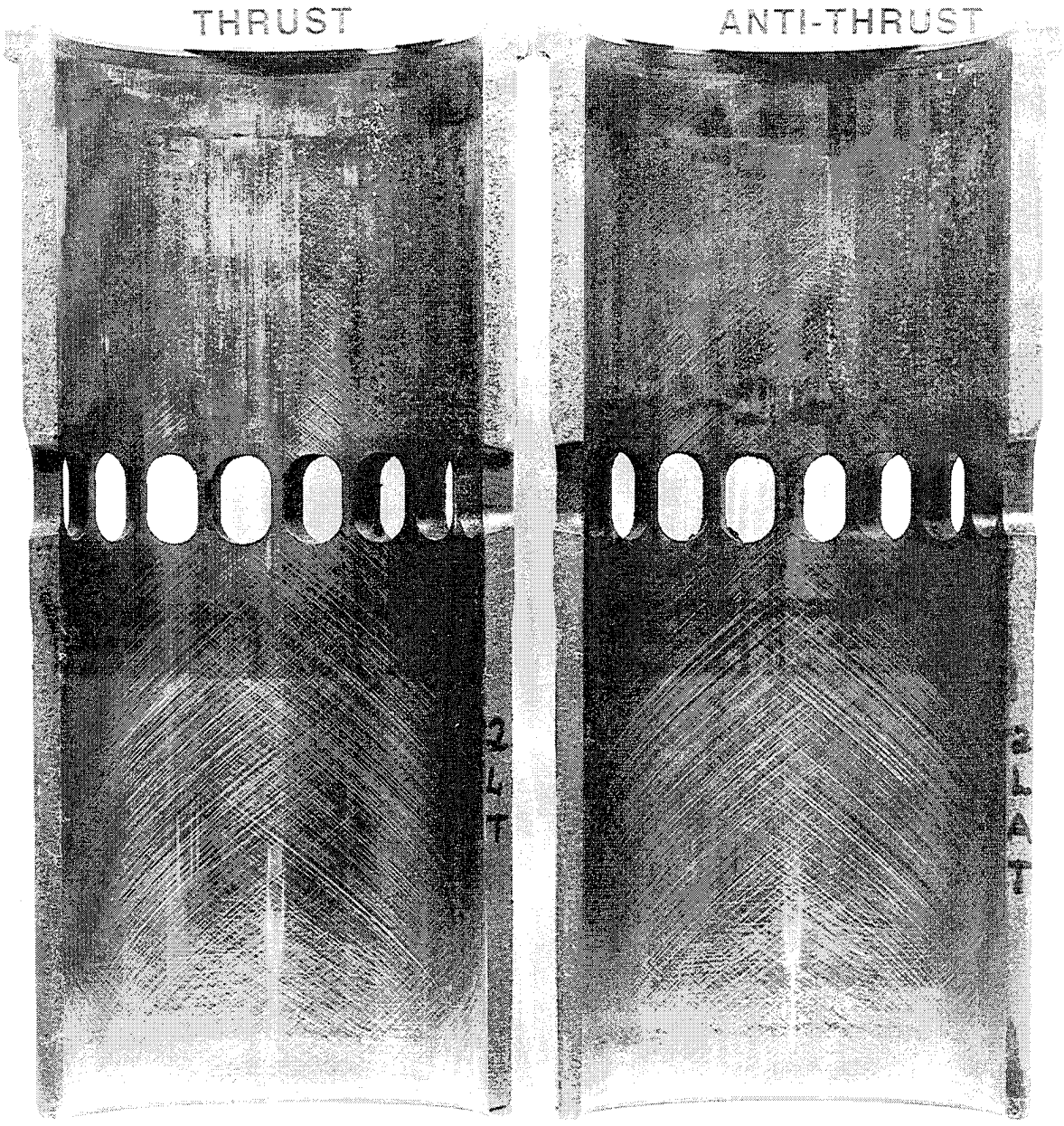
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
3-R



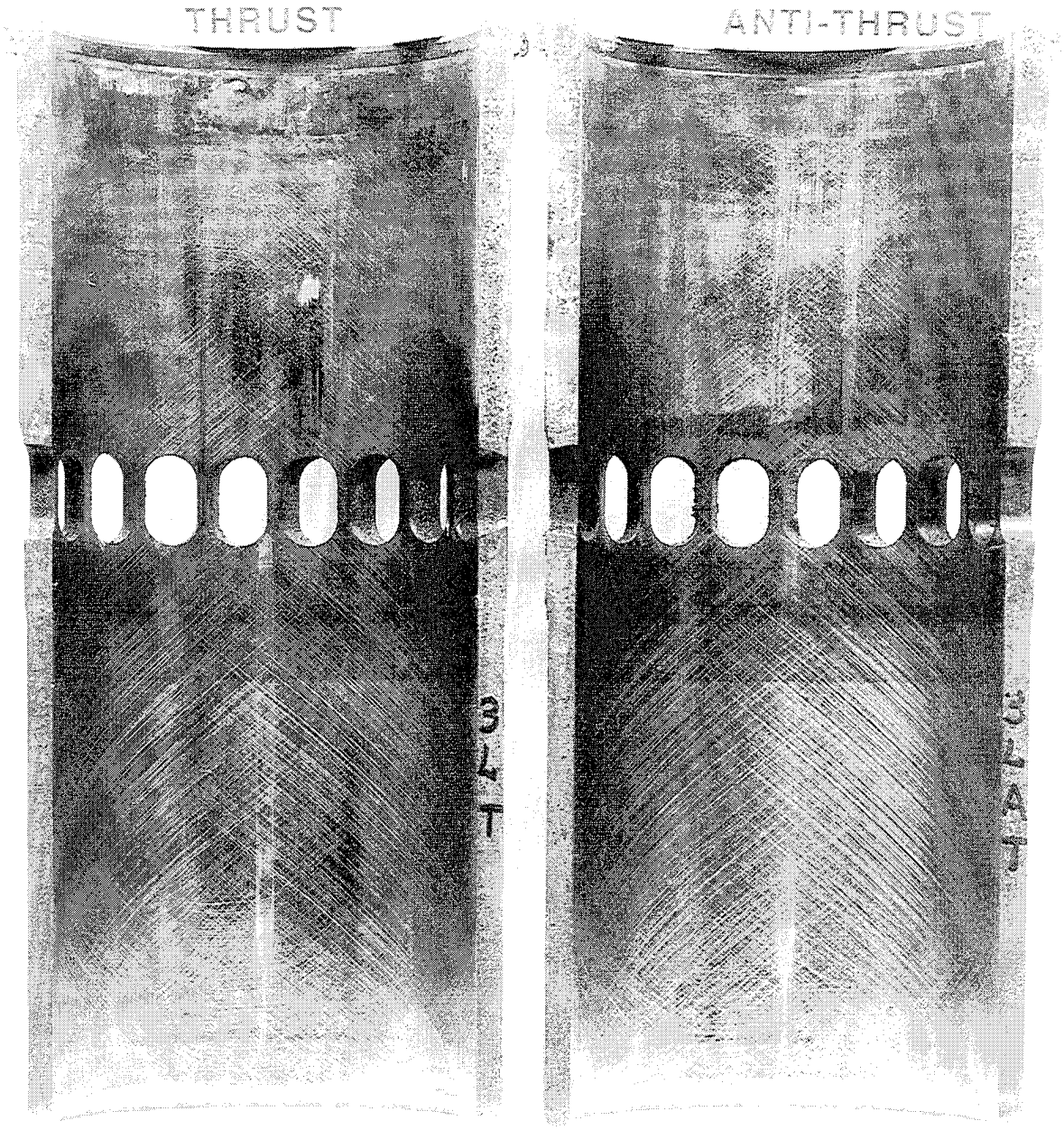
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
1-L



6V53T 57A
AL-19660-L REF DF-2
240 HRS.
2-L

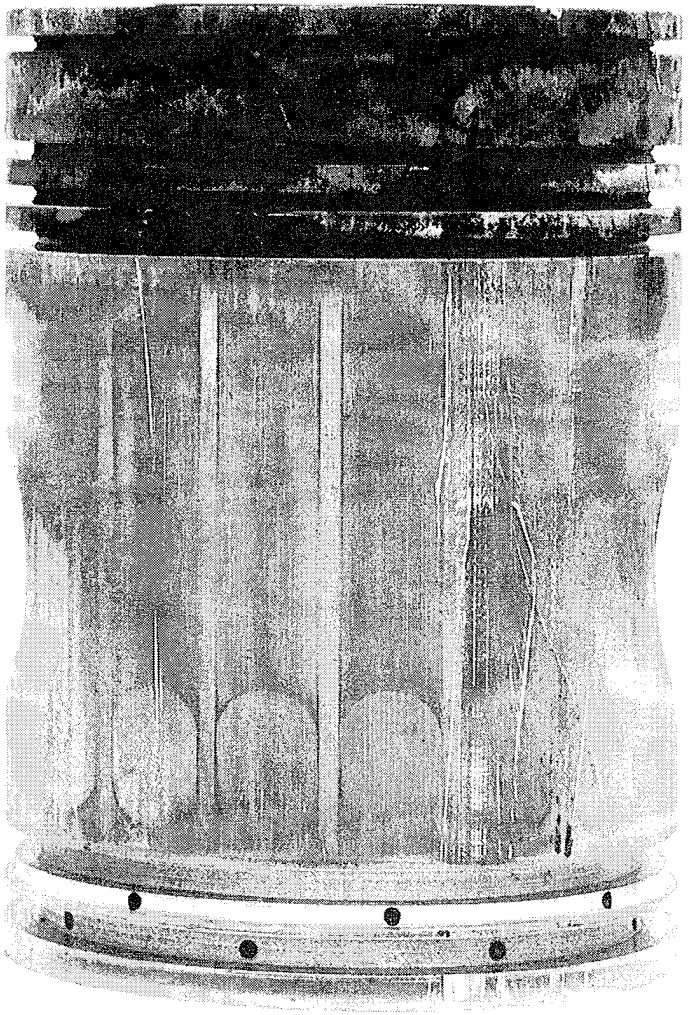


6V53T 57A
AL-19660-L REF DF-2
240 HRS.
3-L



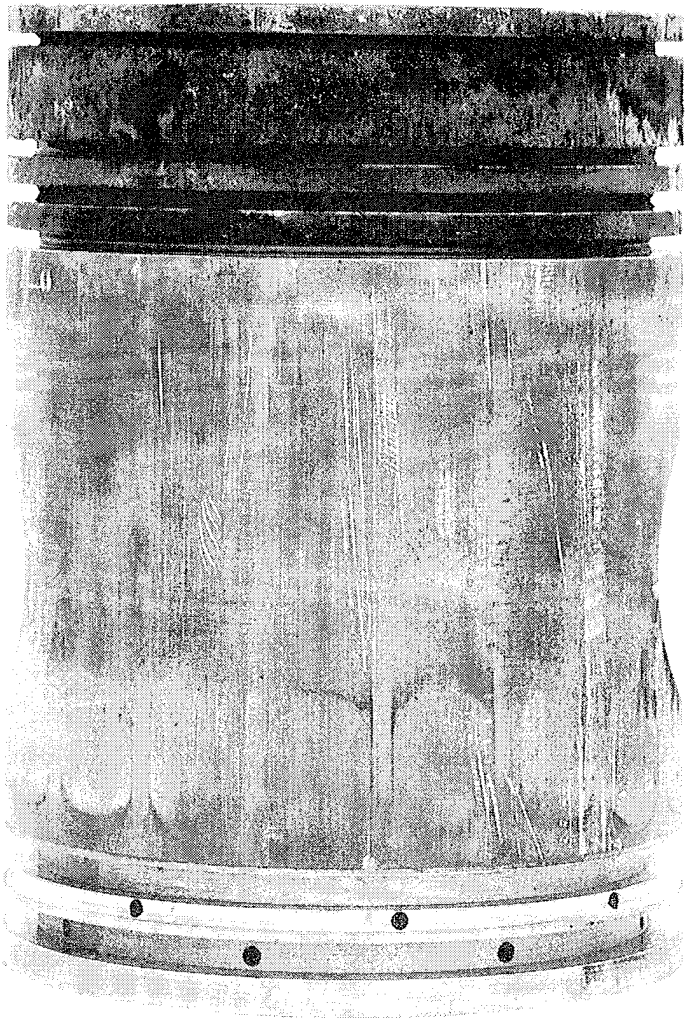
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
1-R-T

6V53T 57A
AL-19660-L REF DF-2
240 HRS.
1-R-AT



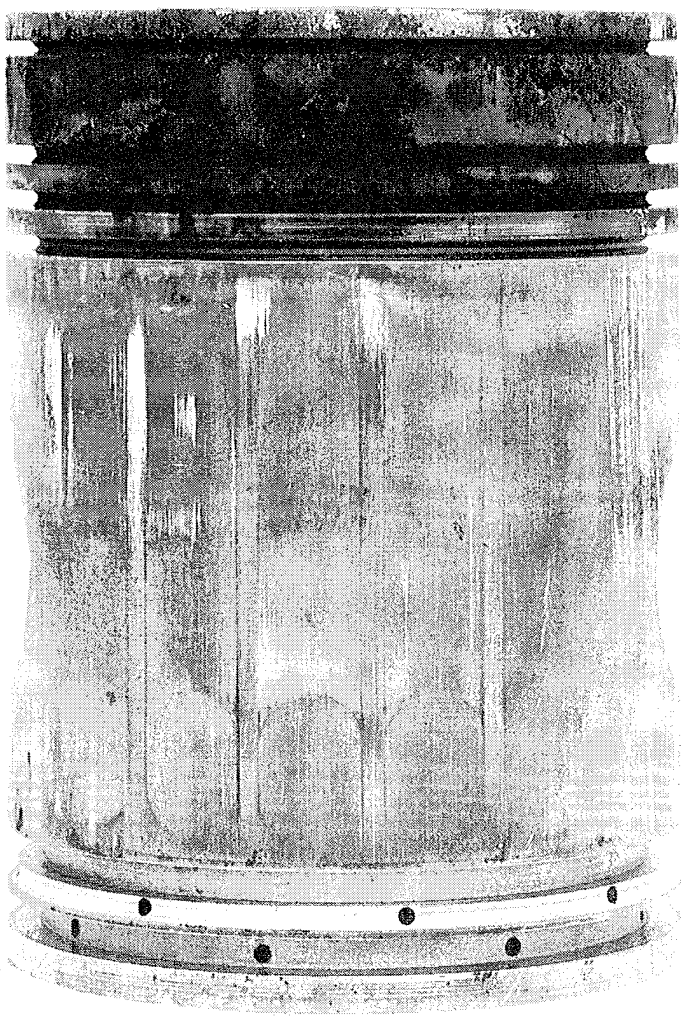
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
2-R-T

6V53T 57A
AL-19660-L REF DF-2
240 HRS.
2-R-AT

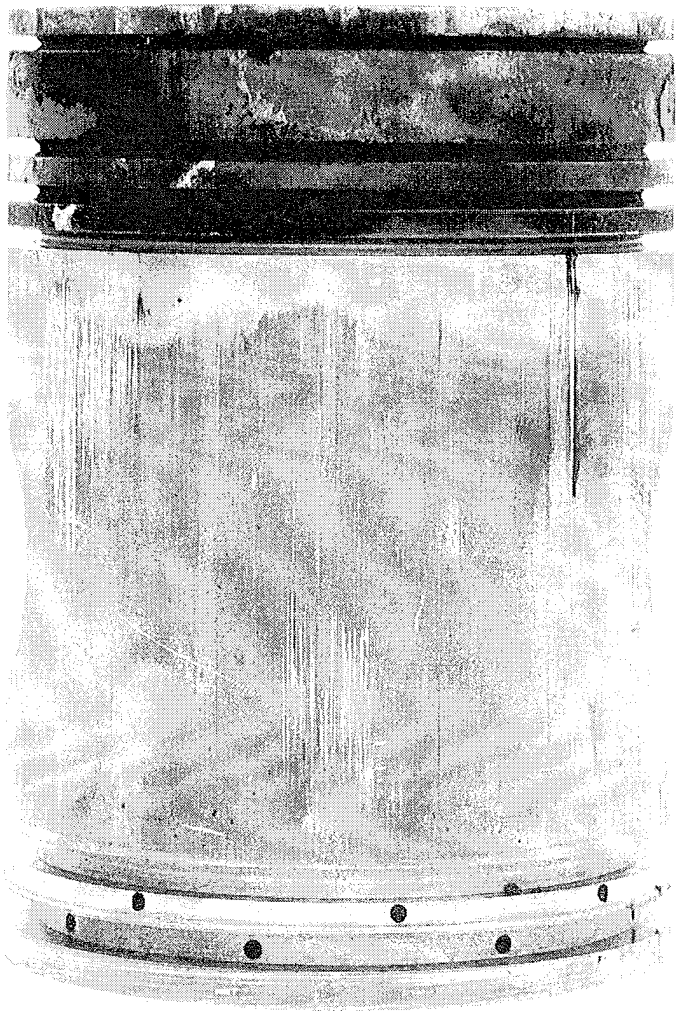


6V53T 57A
AL-19660-L REF DF-2
240 HRS.
3-R-T

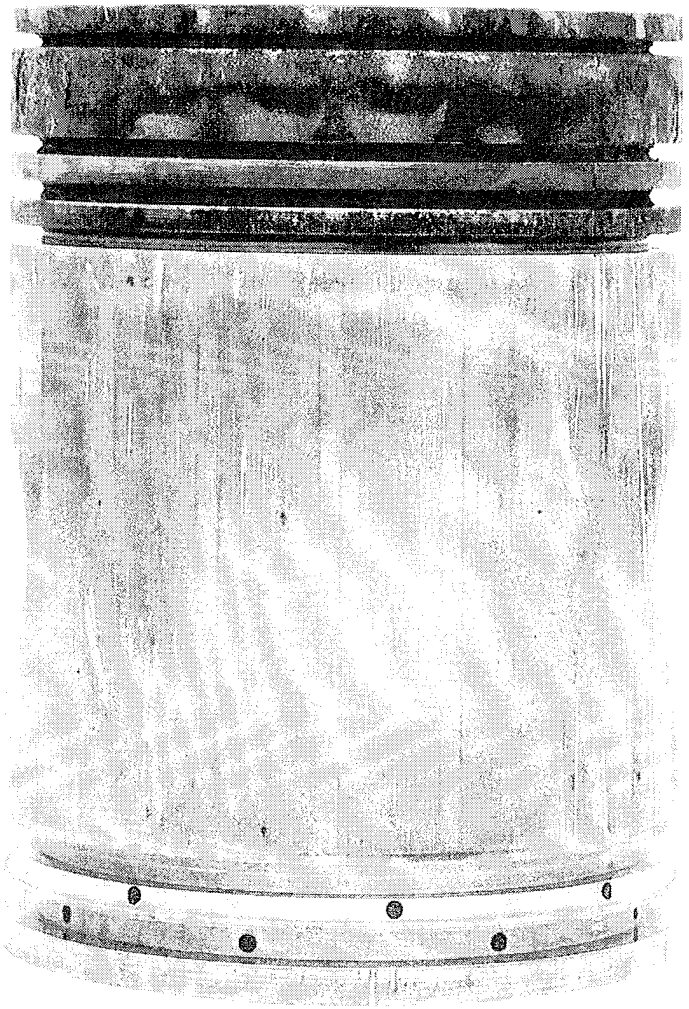
6V53T 57A
AL-19660-L REF DF-2
240 HRS.
3-R-AT



6V53T 57A
AL-19660-L REF DF-2
240 HRS.
1-L-T



6V53T 57A
AL-19660-L REF DF-2
240 HRS.
1-L-AT



APPENDIX D

Test 6V-53T — 58A

Lubricant "C"
AL-19547-L

6V-53T
Test 58A
ENGINE REBUILD MEASUREMENTS
Lubricant: AL-19547-L

	Min		Max		Avg		Specified Limits
	mm	in.	mm	in.	mm	in.	mm (in.) - mm (in.)
CYLINDER BLOCK BORE							
Inside Diameter (Bottom)	110.656	4.3567	110.684	4.3578	110.670	4.3573	110.655 (4.3565) - 110.681 (4.3575) New
							- 110.731 (4.3595) Max
Out-of-Round	0.003	0.0001	0.018	0.0007	0.008	0.0003	
Taper	0.003	0.0001	0.008	0.0003	0.004	0.0002	- 0.038 (0.0015) Max
							- 0.038 (0.0015) Max
CYLINDER LINERS (Installed)							
Inside Diameter	98.434	3.8755	98.459	3.8765	98.447	3.8760	98.430 (3.8752) - 98.468 (3.8767)
Out-of-Round	0.000	0.0000	0.008	0.0003	0.003	0.0001	- 0.038 (0.0015) Max
Taper	0.000	0.0000	0.015	0.0006	0.007	0.0003	- 0.038 (0.0015) Max
Piston Diameter (at Skirt)	98.253	3.8684	98.259	3.8686	98.256	3.8685	98.219 (3.8669) - 98.775 (3.8691)
Piston Skirt-to-Cylinder Liner Clearance	0.175	0.0069	0.201	0.0079	0.191	0.0075	0.155 (0.0061) - 0.249 (0.0098)
COMPRESSION RINGS							
Gap (No. 1, Fire Ring)	0.76	0.030	0.86	0.034	0.80	0.032	0.51 (0.020) - 1.0 (0.040)
Gap (Nos. 2, 3, 4)	0.58	0.023	0.79	0.031	0.72	0.028	0.51 (0.020) - 1.0 (0.040)
RING-TO-GROOVE CLEARANCE							
Top (No. 1, Fire Ring)	0.076	0.0030	0.102	0.0040	0.080	0.0032	0.08 (0.0030) - 0.17 (0.0066)
No. 2, Compression Ring	0.178	0.0070	0.203	0.0080	0.195	0.0077	0.18 (0.0070) - 0.27 (0.0105)
Nos. 3 and 4, Compression Rings	0.102	0.0040	0.152	0.0060	0.142	0.0056	0.13 (0.0050) - 0.22 (0.0085)
OIL CONTROL RINGS (Nos. 5, 6, 7)							
Gap	0.254	0.0100	0.381	0.0150	0.337	0.0133	0.254 (0.0100) - 0.508 (0.020)
Ring-to-Groove Clearance	0.038	0.0015	0.076	0.0030	0.060	0.0024	0.038 (0.0015) - 0.140 (0.0055)
PISTON PIN							
Pin-to-Piston Bushing Clearance	0.071	0.0028	0.081	0.0032	0.075	0.0029	0.064 (0.0025) - 0.864 (0.0034)
Pin-to-Connecting Rod Bushing Clearance	0.030	0.0012	0.043	0.0017	0.039	0.0015	0.025 (0.0010) - 0.048 (0.0019)
Connecting Rod Bearing-to-Journal Clearance	0.023	0.0009	0.041	0.0016	0.035	0.0014	0.028 (0.0011) - 0.104 (0.0041)
Main Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.076 (0.0030) - 0.127 (0.0050)
Camshaft Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.114 (0.0045) - 0.152 (0.0060)

Detroit Diesel 6V-53T
Test 58A
FTM-355 TRACKED VEHICLE CYCLE ENDURANCE TEST — OPERATING CONDITIONS SUMMARY
Lubricant: AL-19547-L
Fuel: Reference No. 2 Diesel Fuel

	Maximum Power Mode, 2,800 rpm		Maximum Torque Mode, 2,200 rpm	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	2,801	1	2,201	1
Torque, N-m (lb-ft)	759 (555)	3 (2)	852 (623)	0.51 (1)
Fuel Consumption, kg/hr (lb/hr)	54.83 (121.0)	0.507 (1.1)	46.79 (103.3)	0.29 (0.6)
Observed Power, kW (bhp)	221 (296)	0.8 (1.1)	195 (261)	0.3 (0.4)
BSFC, g/kW-hr (lb/bhp-hr)	0.249 (0.409)	0.0027 (0.0045)	0.241 (0.396)	0.0017 (0.0028)
Temperatures, °C (°F)				
Exhaust Before Turbo	538 (1,001)	3.5 (6.2)	538 (1,001)	2.2 (4.0)
Exhaust After Turbo	411 (771)	3.0 (5.4)	422 (791)	1.8 (3.2)
Water Jacket Inlet	72 (161)	0.4 (0.8)	72 (161)	0.5 (0.8)
Water Jacket Outlet	77 (171)	0.4 (0.7)	77 (170)	0.4 (0.7)
Oil Sump	111 (232)	0.9 (1.6)	106 (224)	0.7 (1.2)
Fuel at Filter	35 (94)	0.7 (1.3)	35 (94)	0.4 (0.7)
Inlet Air	32 (90)	0.7 (1.3)	32 (90)	0.5 (0.9)
Airbox	144 (292)	2.2 (4.0)	112 (234)	1.0 (1.8)
Air After Compressor	130 (265)	1.5 (2.8)	107 (224)	1.0 (1.8)
Blowby	60 (140)	1.3 (2.4)	51 (123)	1.3 (2.4)
Oil Gallery	100 (211)	0.2 (0.4)	95 (203)	0.3 (0.5)
Wet Bulb Temperature	35 (95)	0.7 (1.3)	35 (95)	0.0 (0.0)
Dry Bulb Temperature	39 (103)	2.1 (3.8)	41 (105)	2.1 (3.9)
Pressures				
Exhaust Before Turbo, kPa (psi)	98.39 (14.3)	1.144 (0.17)	64.91 (9.4)	0.244 (0.04)
Compressor Discharge, kPa (psi)	102.38 (14.8)	0.982 (0.14)	77.16 (11.2)	0.935 (0.14)
Blower Discharge, kPa (psi)	124.3 (18.0)	0.829 (0.12)	75.00 (10.9)	1.367 (0.20)
Fuel Transfer Pump, kPa (psi)	481.3 (69.8)	0.640 (0.09)	458.60 (66.5)	0.903 (0.13)
Oil Gallery, kPa (psi)	276.0 (40.0)	4.533 (0.66)	245.80 (35.6)	3.296 (0.48)
Intake Vacuum, kPa (in. Hg)	31.39 (9.30)	0.169 (0.05)	19.26 (5.70)	0.217 (0.06)
Barometric Pressure, kPa (in. Hg)	98.46 (29.07)	0.025 (0.10)	98.49 (29.08)	0.110 (0.44)
Exhaust Common, kPa (in. H_2O)	6.11 (24.5)	0.041 (0.16)	4.26 (17.10)	0.006 (0.02)
Blowby, kPa (in. H_2O)	0.49 (2.0)	0.211 (0.06)	0.13 (0.50)	0.131 (0.04)

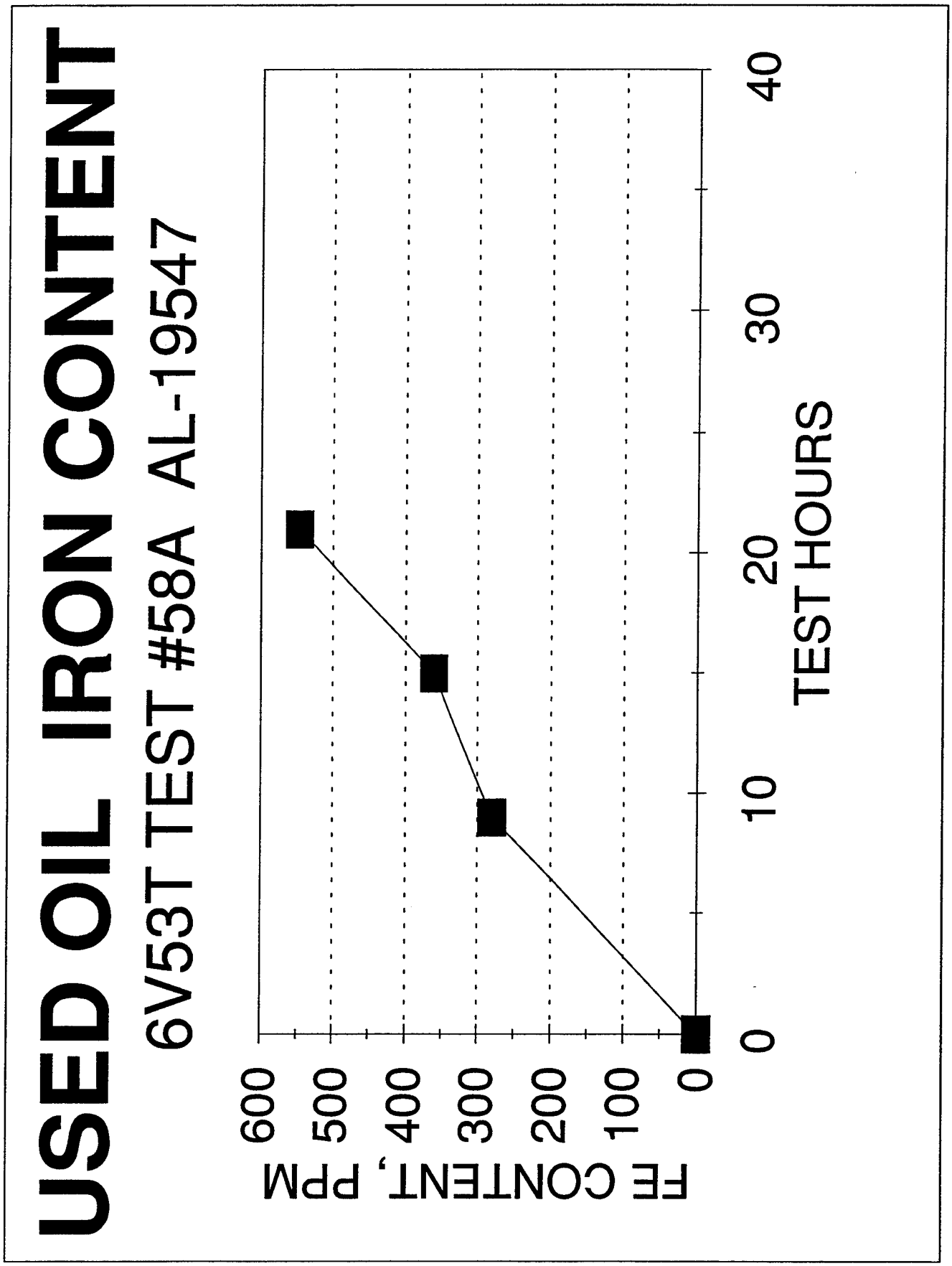
6V-53T
Test 58A
LUBRICANT ANALYSIS
Lubricant: AL-19547-L

Lubricant Analysis	ASTM Test Method	Test Time, hr 0	Test Time, hr 21.5
Kinematic Viscosity, cSt, at			
40°C	D 445	51.14	44.72
100°C	D 445	10.86	9.25
Total Acid Number, mg KOH/g	D 664	1.44	2.06
Total Base Number, mg KOH/g	D 664	7.92	3.18
Pentane B Insolubles, wt%	D 893	ND*	0.02
Toluene B Insolubles, wt%	D 893	ND	0.01
Flash Point, °C	D 92	210	211

* ND = Not Determined

6V-53T
Test 58A
TOTAL OIL CONSUMPTION AND WEAR METALS BY XRF
Lubricant: AL-19528-L

Test Time, hr	Total Oil Consumed kg	Total Oil Consumed lb	Wear Metals, ppm Fe	Wear Metals, ppm Cu
0	--	--	<20	<20
9	--	--	280	<20
15	--	--	361	<20
21.5	2.29	5.04	547	<20
	kg/hr	lb/hr		
Average Oil Consumption Rate	0.11	0.23		


USED OIL IRON CONTENT
6V53T TEST #58A AL-19547
FE CONTENT, PPM
600
500
400
300
200
100
0
0
10
20
30
40
TEST HOURS

6V-53T
Test 58A
POST-TEST ENGINE CONDITIONS AND DEPOSITS
Lubricant: AL-19547-L

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Avg
CYLINDER LINER							
Intake Port Plugging							
% Restriction	<1	<1	<1	<1	<1	<1	<1
Liner Scuffing, % Area							
Thrust	47	24	100	97	100	88	76.00
Antithrust	17	16	100	88	100	97	69.67
% Total Area	32.0	20.0	100.0	92.5	100.0	92.5	72.83
						Overall:	72.83
					Overall, Five Cylinders (w/o 3L):		67.40
% Area Bore Polished							
Thrust	0	5	0	0	0	0	0.83
Antithrust	0	0	0	1	0	0	0.17
% Avg Area Bore Polished	0.0	2.5	0.0	0.5	0.0	0.0	0.50
						Overall:	0.50
					Overall, Five Cylinders (w/o 3L):		0.60
Avg Liner Distress	32	21	100	92.5	100	92.5	73.00
					Overall, Five Cylinders (w/o 3L):		67.60
RINGS							
Ring Face Distress, Demerits							
No. 1	32.50	6.00	75.00	62.50	73.75	68.75	53.08
No. 2	56.25	21.50	75.00	42.50	73.75	38.75	51.29
No. 3	57.50	28.00	75.00	30.75	68.75	32.50	48.75
No. 4	63.75	41.50	68.75	36.75	68.75	32.50	52.00
						Overall:	51.28
PISTONS							
Piston Skirt Rating*							
Thrust	18% SC & S	4% SC & S	5% PM, 14% SC & S	24% SC & S	3% PM, 18% SC & S	20% SC & S	
Antithrust	4% SC & S	2% SC & S	7% PM, 9% SC & S	11% SC & S	1% PM, 16% SC & S	16% SC & S	
Piston WTD Rating**	136.60	146.72	200.12	147.24	174.24	153.22	
Ring Sticking***							
No. 1	F	F	BR	F, PC	BR	F, PC	
No. 2	F	F	F, TC	F	F	F	
No. 3	F	F	F	F	F		
No. 4	F	F	F	F	F	F	
EXHAUST VALVES							
Deposits							
Head+	100 LC	100 LC	100 LC	100 LC	100 LC	100 LC	
Face	← Trace Amount of Carbon and Ash Embedment →						
Tulip++	0.3	0.3	0.3	0.3	0.3	0.3	
Stem	← All Stems 3 to 5% #9 Lacquer →						
Surface Conditions							
Freeness in Guide	← Normal →						
Head	← Normal →						
Face	← Normal →						
Seat	← Normal →						
Stem	← Normal →						
Tip	← Normal →						

* Lt = Light, S = Scratches, PM = Plating Melted, N = Normal, SC = Scuffing, and B = Burn

** CRC Weighted Total Deposits (0 = Least, 900 = Most)

*** F = Free, PC = Partially Collapsed, TC = Totally Collapsed, BR = Broken, and CS = Cold Stuck

\+ HC = Hard Carbon, LC = Light Carbon, MC = Medium Carbon — the number indicates percentage

++ The higher the number, the darker the lacquer (0 = Lightest, 9 = Darkest)

6V-53T
Test 58A
LINER AND RING FACE DISTRESS SUMMARY
Lubricant: AL-19547-L

Liner Distress	
Six-Cylinder Avg	73.0
Five-Cylinder Avg (w/o 3L)	67.6
Ring Face Distress, Nos. 2 and 3	
Six-Cylinder Avg	50.02
Five-Cylinder Avg (w/o 3L)	45.03

6V-53T
Test 58A
WEAR MEASUREMENTS
Lubricant: AL-19547-L

Cylinder Liner Bore Diameter Changes

	Cylinder Number											
	1L				2L				3L			
	T-AT*		F-B		T-AT		F-B		T-AT		F-B	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Top	0.018	0.0007	0.005	0.0002	0.046	0.0018	0.000	0.0000	0.069	0.0027	0.053	0.0021
Middle	0.013	0.0005	0.000	0.0000	0.008	0.0003	0.000	0.0000	0.028	0.0011	0.056	0.0022
Bottom	0.008	0.0003	–0.003	–0.0001	0.003	0.0001	0.005	0.0002	–0.005	–0.0002	0.003	0.0001

	Cylinder Number											
	1R				2R				3R			
	T-AT		F-B		T-AT		F-B		T-AT		F-B	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Top	0.063	0.0025	0.025	0.0010	0.028	0.0011	0.046	0.0018	0.058	0.0023	0.069	0.0027
Middle	0.023	0.0009	0.023	0.0009	0.015	0.0006	0.033	0.0013	0.025	0.0010	0.025	0.0010
Bottom	–0.010	–0.0004	–0.003	–0.0001	–0.005	–0.0002	0.005	0.0002	–0.003	–0.0001	0.000	0.0000

Average Change

	T-AT		F-B	
	mm	in.	mm	in.
Top	0.047	0.0018	0.033	0.0013
Middle	0.019	0.0007	0.023	0.0009
Bottom	–0.002	–0.0001	0.001	0.0000

Piston Ring End Gap Change

	Cylinder Number													
	1L		2L		3L		1R		2R		3R		Average Change	
Ring No.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
1	0.025	0.0010	0.000	0.0000	Broken		0.178	0.0070	Broken		0.203	0.0080	0.063	0.0025
2	0.000	0.0000	0.051	0.0020	0.025	0.0010	0.076	0.0030	0.229	0.0090	0.127	0.0050	0.072	0.0028
3	–0.025	–0.0010	0.025	0.0010	0.229	0.0090	0.025	0.0010	0.127	0.0050	0.051	0.0020	0.174	0.0068
4	0.025	0.0010	0.025	0.0010	0.051	0.0020	0.000	0.0000	0.025	0.0010	0.051	0.0020	0.109	0.0043
5	0.178	0.0070	0.178	0.0070	2.184	0.0860	0.229	0.0090	0.203	0.0080	0.305	0.0120	0.128	0.0050
6	0.152	0.0060	0.178	0.0070	0.533	0.0210	0.279	0.0110	0.152	0.0060	0.432	0.0170	0.144	0.0057
7	0.152	0.0060	0.152	0.0060	0.508	0.0100	0.254	0.0100	0.127	0.0050	0.432	0.0170	0.135	0.0053

Overall Average Change

mm	in.
0.118	0.0046

* T-AT = Thrust-Antithrust, F-B = Front-Back

6V-53T
Test 58A
WEAR MEASUREMENTS (CONT'D)
Lubricant: AL-19547-L

Average Piston Radial Width Change

	Cylinder Number													
	1L		2L		3L		1R		2R		3R		Average Change	
Ring No.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
1	–0.038	–0.0015	–0.027	–0.0011	–0.081	–0.0032	–0.077	–0.0030	–0.076	–0.0030	–0.089	–0.0035	–0.065	–0.0025
2	–0.029	–0.0011	–0.029	–0.0012	–0.058	–0.0023	–0.045	–0.0018	–0.072	–0.0028	–0.061	–0.0024	–0.049	–0.0019
3	–0.024	–0.0009	–0.025	–0.0010	–0.072	–0.0028	–0.045	–0.0018	–0.053	–0.0021	–0.025	–0.0010	–0.041	–0.0016
4	–0.029	–0.0012	–0.035	–0.0014	–0.055	–0.0022	–0.036	–0.0014	–0.044	–0.0017	–0.051	–0.0020	–0.042	–0.0016

Overall Average Change

mm	in.
–0.049	–0.0019

6V-53T RING FACE DISTRESS
(Six Cylinders)

Sponsor Code: AL-19547-L
Hours: 21.5

Date: 07-15-91

SwRI Code: BFLRF
Block: 01 Test 58A

Cylinder No.	Ring No.	Extreme (1.00)		Heavy (0.75)		Medium (0.50)		Light (0.25)		Totals	
		% Area	Demerits	% Area	Demerits	% Area	Demerits	% Area	Demerits	% Area	Demerits
1L	1	0	0.00	30	22.50	15	7.50	10	2.50	55	32.50
	2	0	0.00	50	37.50	25	12.50	25	6.25	100	56.25
	3	0	0.00	50	37.50	30	15.00	20	5.00	100	57.50
	4	0	0.00	70	52.50	15	7.50	15	3.75	100	63.75
2L	1	0	0.00	2	1.50	3	1.50	12	3.00	17	6.00
	2	0	0.00	12	9.00	12	6.00	26	6.50	50	21.50
	3	0	0.00	25	18.75	2	1.00	33	8.25	60	28.00
	4	0	0.00	31	23.25	4	2.00	65	16.25	100	41.50
3L	1	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	2	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	3	0	0.00	100	75.00	0	0.00	0	0.00	100	75.00
	4	0	0.00	85	63.75	5	2.50	10	2.50	100	68.75
1R	1	0	0.00	70	52.50	10	5.00	20	5.00	100	62.50
	2	0	0.00	30	22.50	10	5.00	60	15.00	100	42.50
	3	0	0.00	8	6.00	7	3.50	85	21.25	100	30.75
	4	0	0.00	20	15.00	7	3.50	73	18.25	100	36.75
2R	1	0	0.00	95	71.25	5	2.50	0	0.00	100	73.75
	2	0	0.00	95	71.25	5	2.50	0	0.00	100	73.75
	3	0	0.00	85	63.75	5	2.50	10	2.50	100	68.75
	4	0	0.00	85	63.75	5	2.50	10	2.50	100	68.75
3R	1	0	0.00	85	63.75	5	2.50	10	2.50	100	68.75
	2	0	0.00	25	18.75	5	2.50	70	17.50	100	38.75
	3	0	0.00	10	7.50	10	5.00	80	20.00	100	32.50
	4	0	0.00	10	7.50	10	5.00	80	20.00	100	32.50

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	472	318.50	78.67	53.08
2	550	307.75	91.67	51.29
3	560	292.50	93.33	48.75
4	600	312.00	100.00	52.00
2 & 3	1,110	600.25	92.50	50.02

6V-53T RING FACE DISTRESS
(Five Cylinders)

Sponsor Code: AL-19547-L
Hours: 21.5

Date: 07-15-91

SwRI Code: BFLRF
Block: 01 Test 58A

Cylinder 3L Eliminated

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	372	243.50	74.40	48.70
2	450	232.75	90.00	46.55
3	460	217.50	92.00	43.50
4	500	243.25	100.00	48.65
2 & 3	910	450.25	91.00	45.03

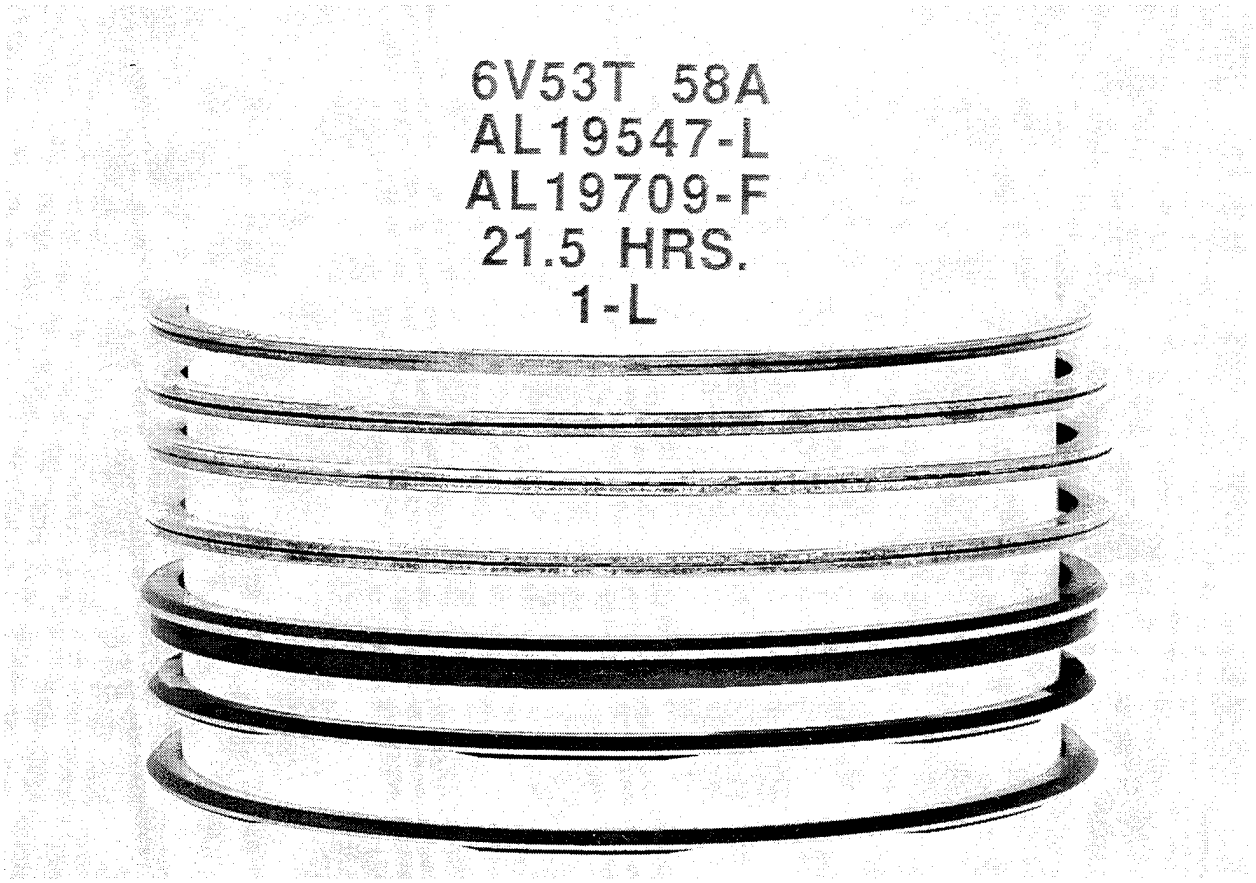
6V-53T
PISTON DEMERIT SUMMARY

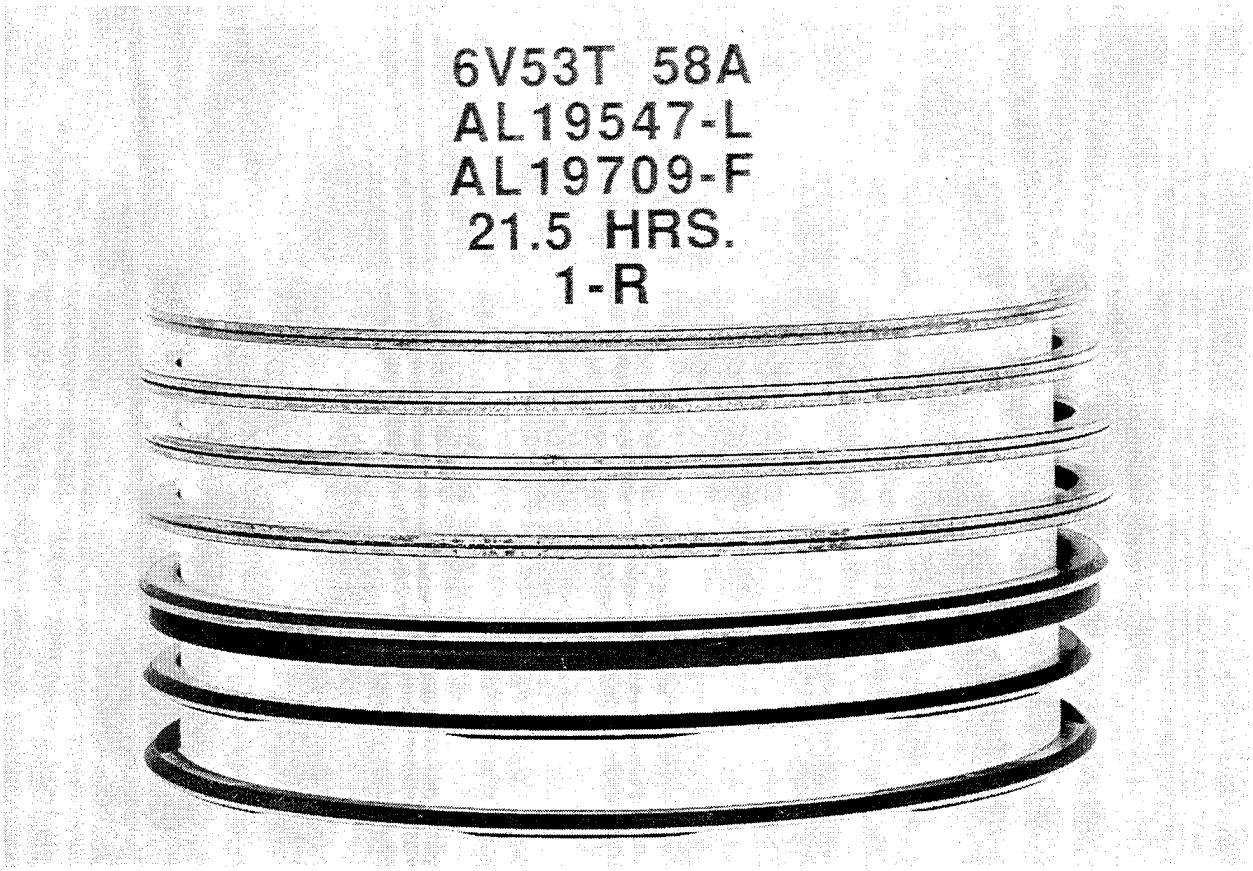
Sponsor Code: AL-19547-L
Hours: 21.5
Date: 07-15-91
SwRI Code: BFLRF
Block: 01 Test 58A

	Piston 1L	Piston 2L	Piston 3L	Piston 1R	Piston 2R	Piston 3R
Carbon (Grooves)	56.25	62.50	92.50	67.50	87.50	66.25
Carbon (Lands)	65.00	69.25	102.75	64.00	80.00	76.25
Lacquer (Grooves)	8.10	7.25	1.12	8.37	2.12	4.72
Lacquer (Lands)	7.25	7.72	3.75	7.37	4.62	6.00
Total Demerits	136.60	146.72	200.12	147.24	174.24	153.22

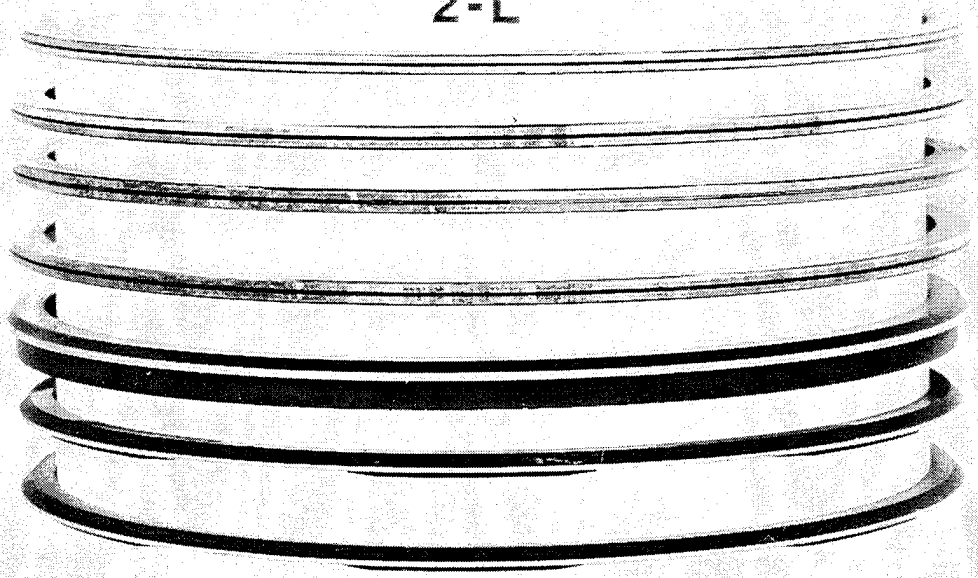
Average of All Six Pistons = 159.69

Average of Five Pistons (w/o 3L) = 151.60

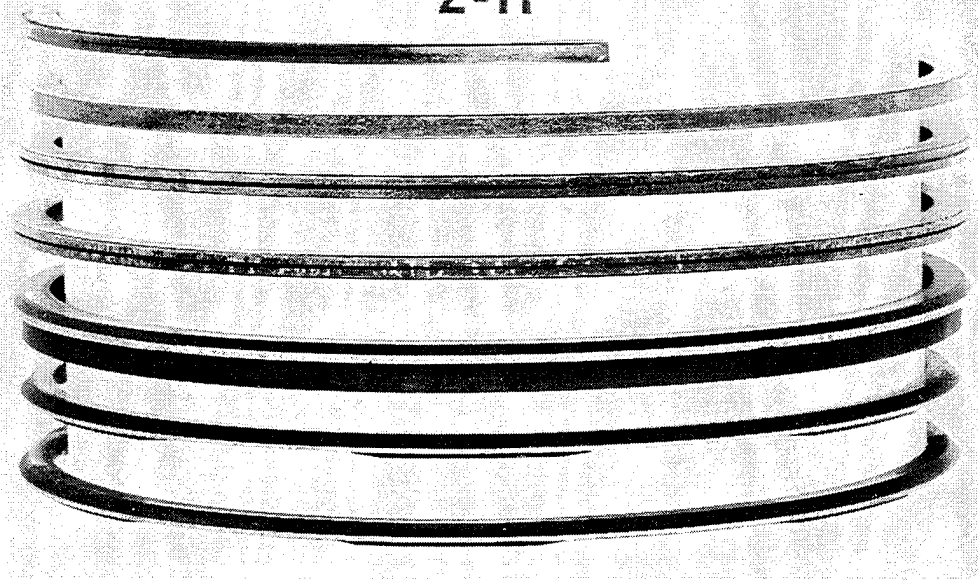

6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
1-L

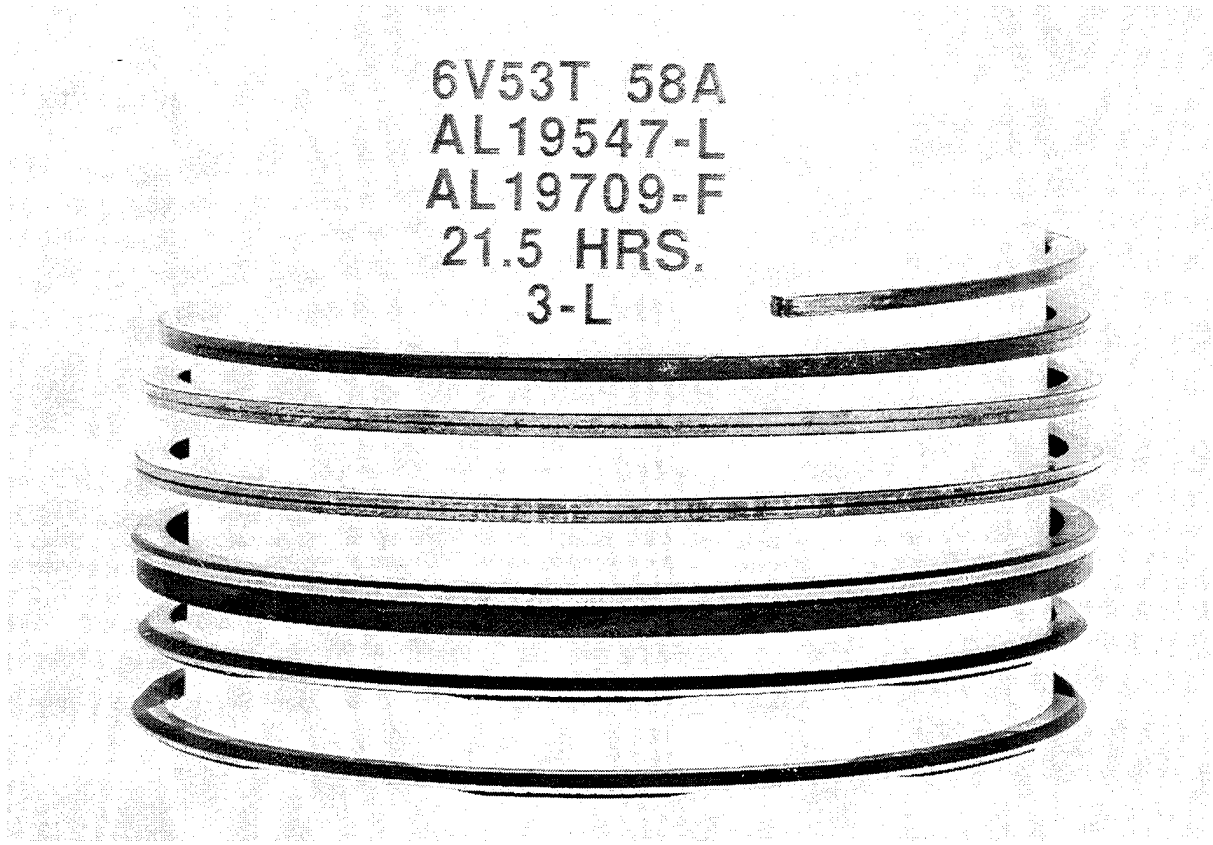

6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
1-R

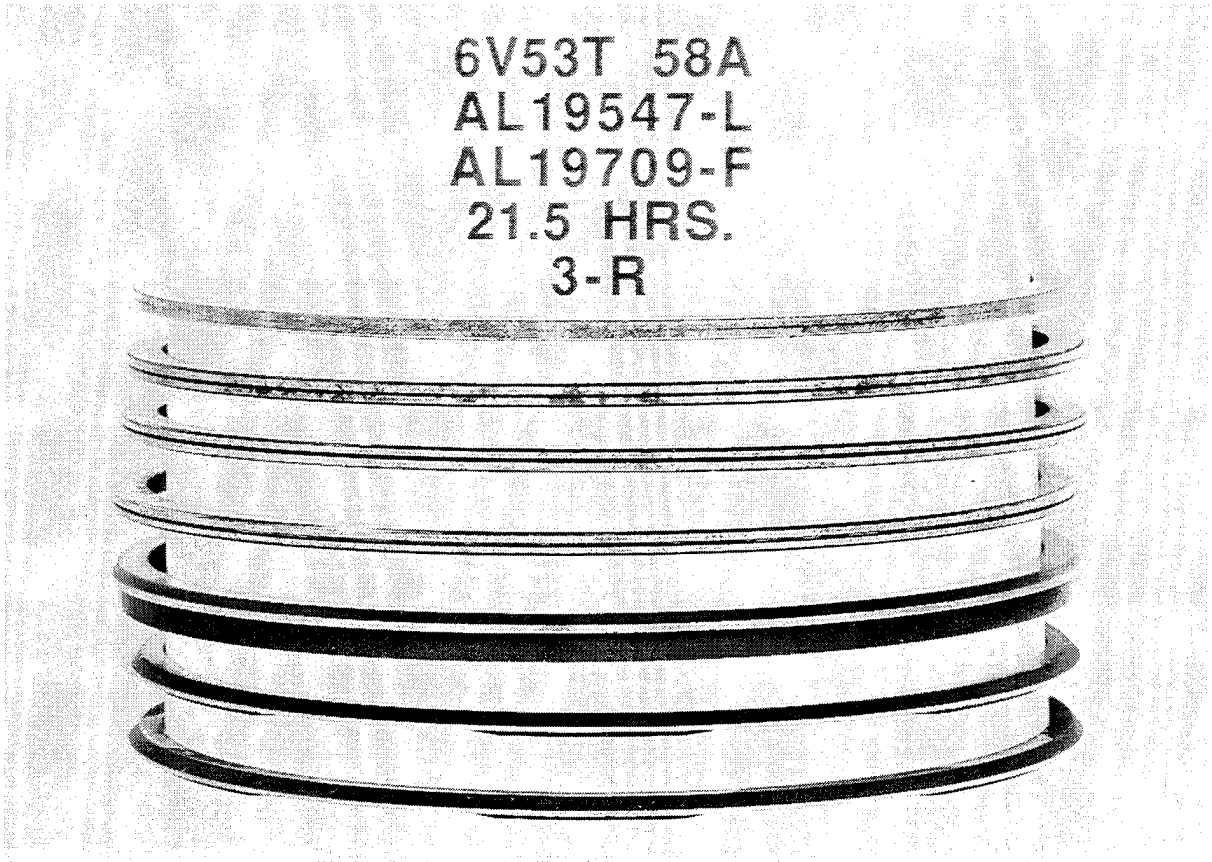
6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
2-L



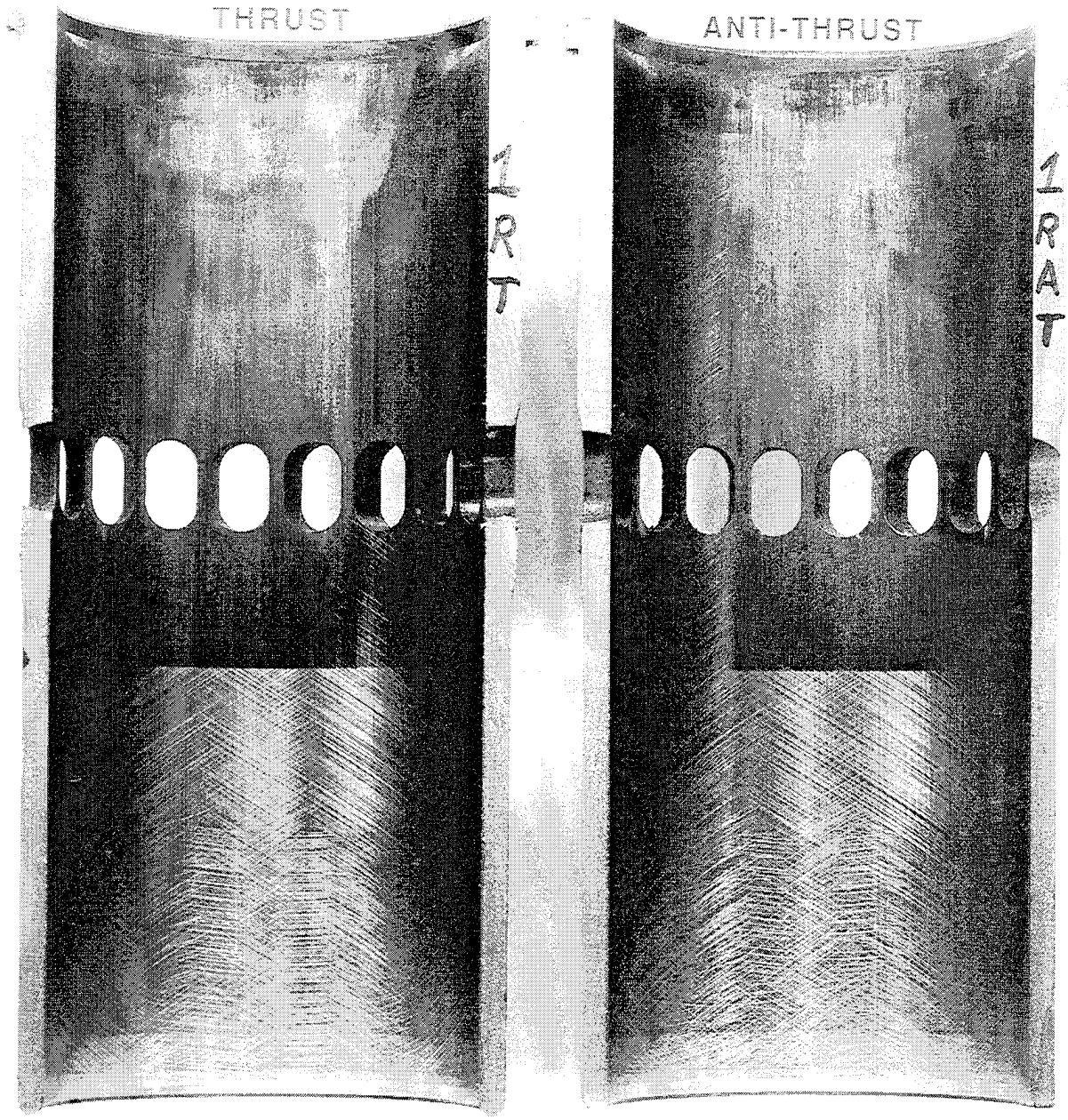
6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
2-R




6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
3-L


6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
3-R

6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
1-R



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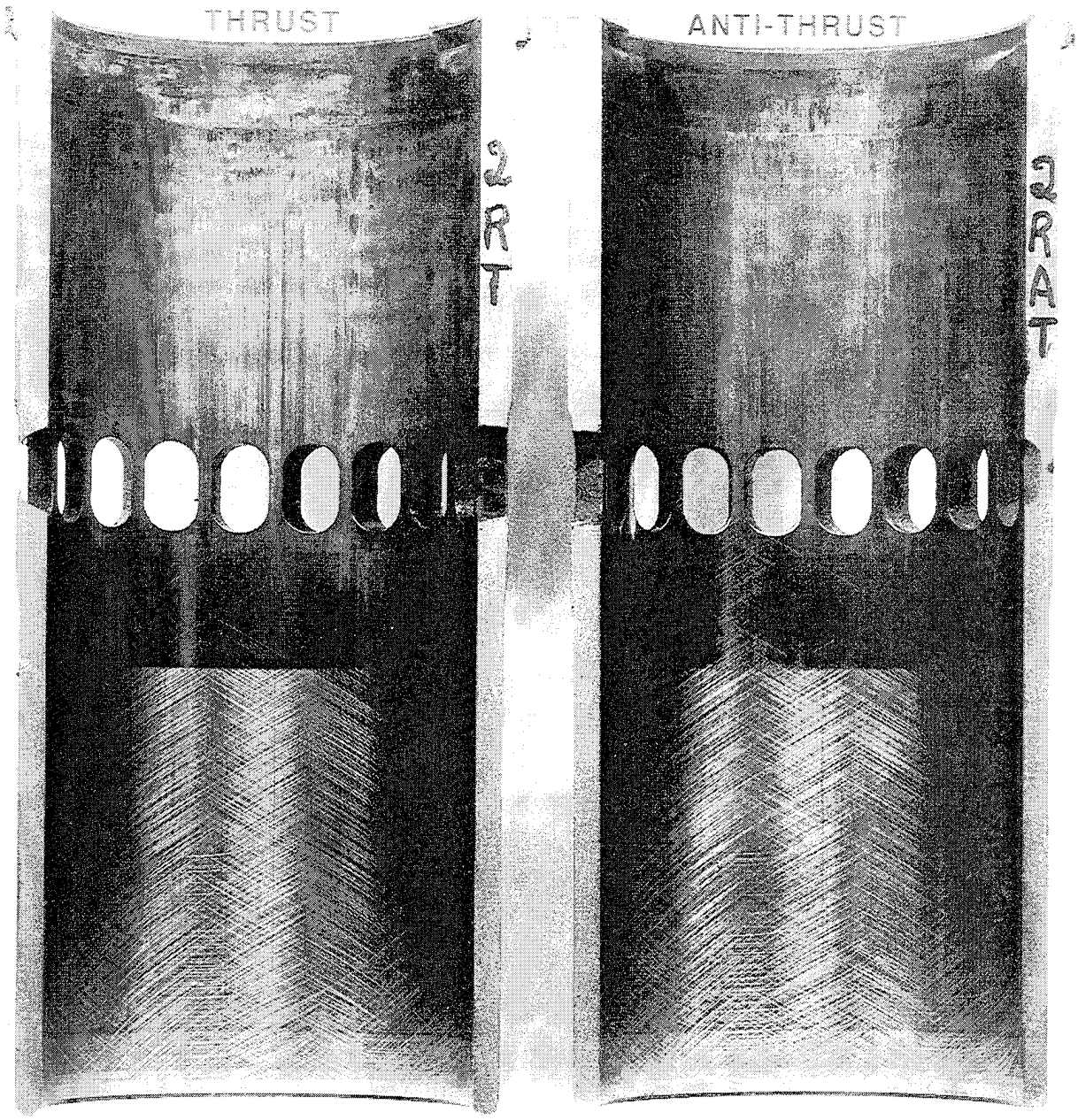
AL19547-L
AL19709-F
21.5 HRS.
2-R



6V53T 68A
AL19547-L
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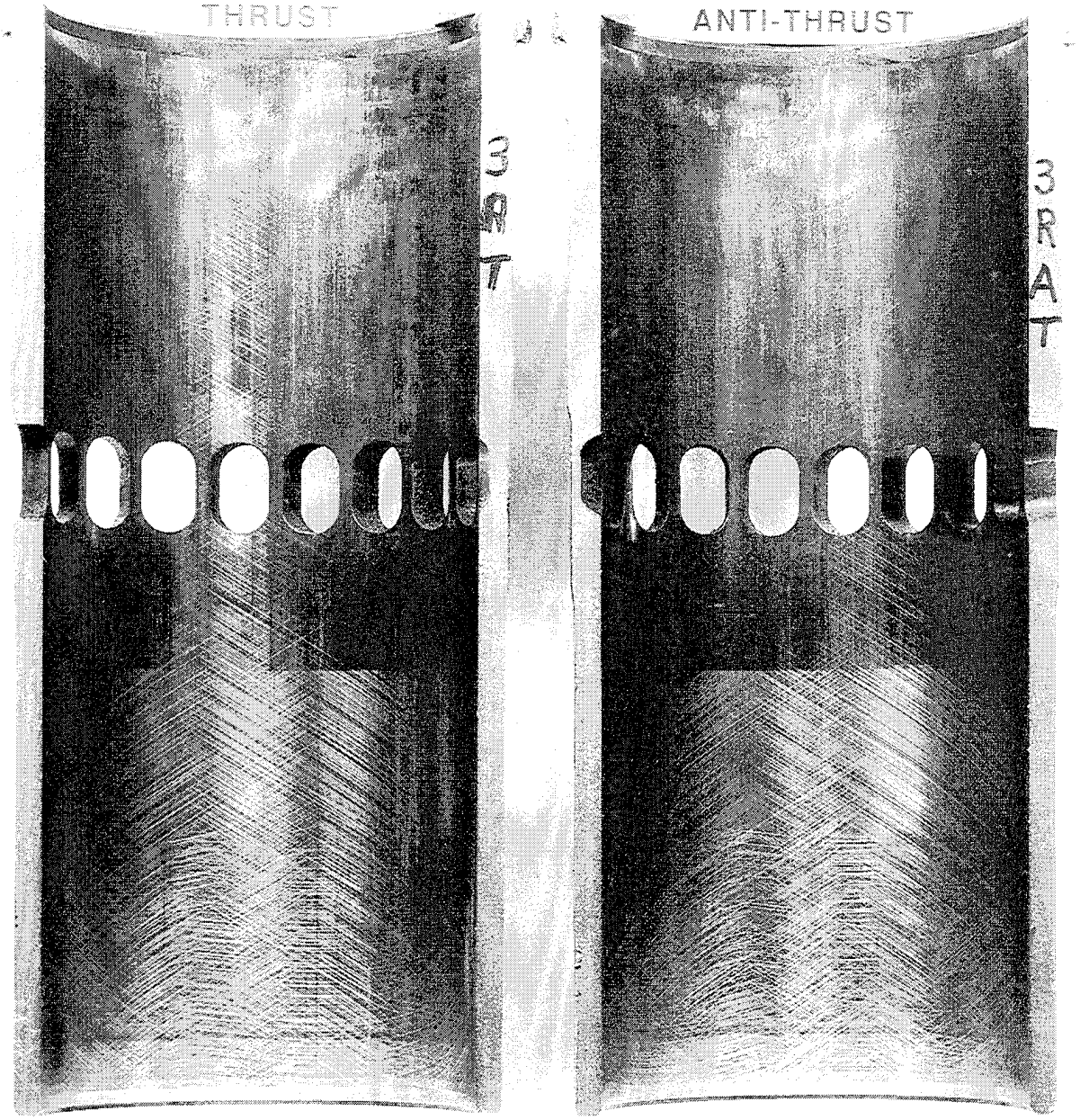
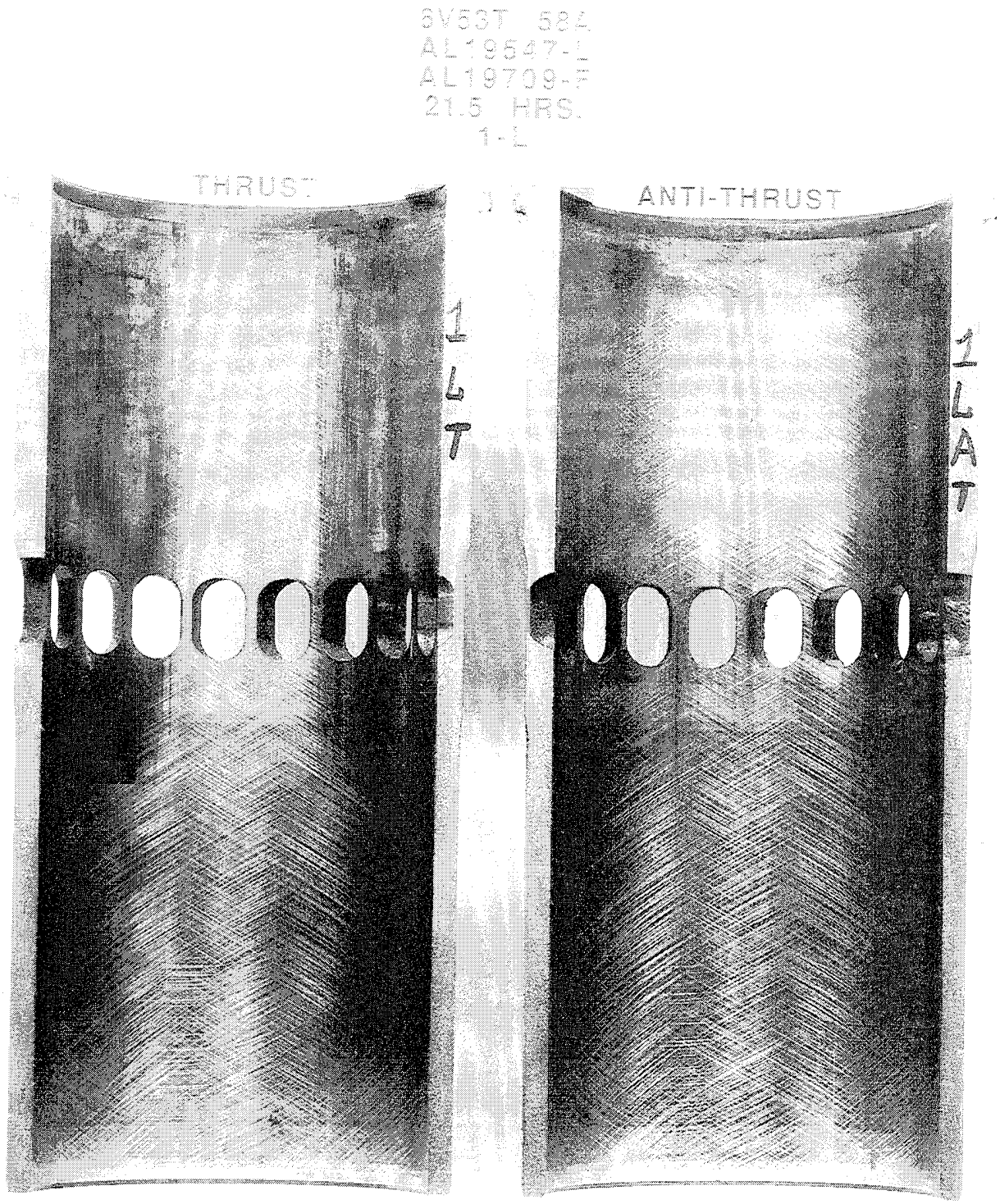
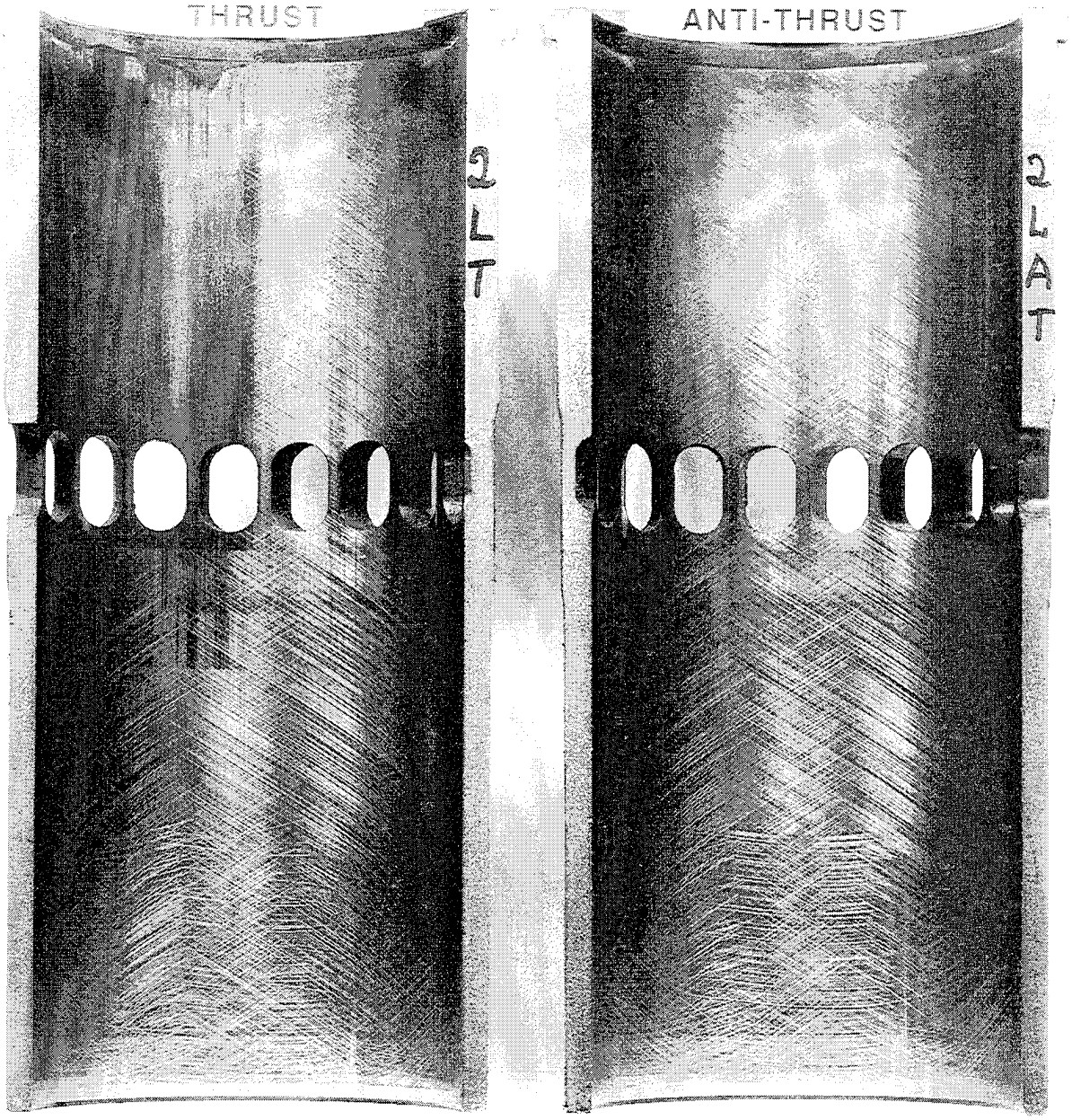
3-R




3V53T 58L
AL19547-L
AL19709-F
21.5 HRS.
1-L
THRUST
1 LT
ANTI-THRUST
1 LAT

6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
2-L



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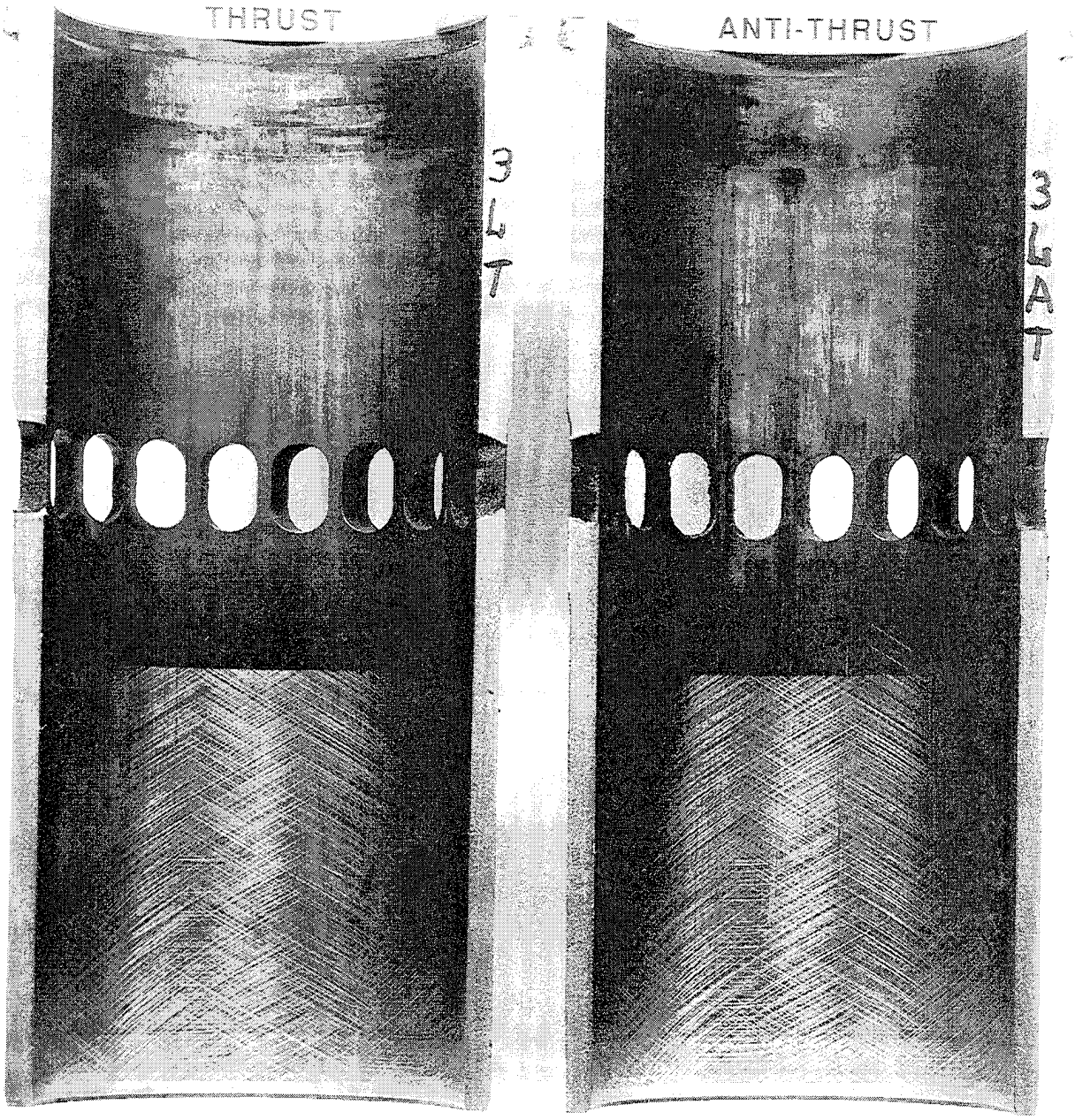
AL19547-L
AL19709-F
21.6 HRS.
3-L



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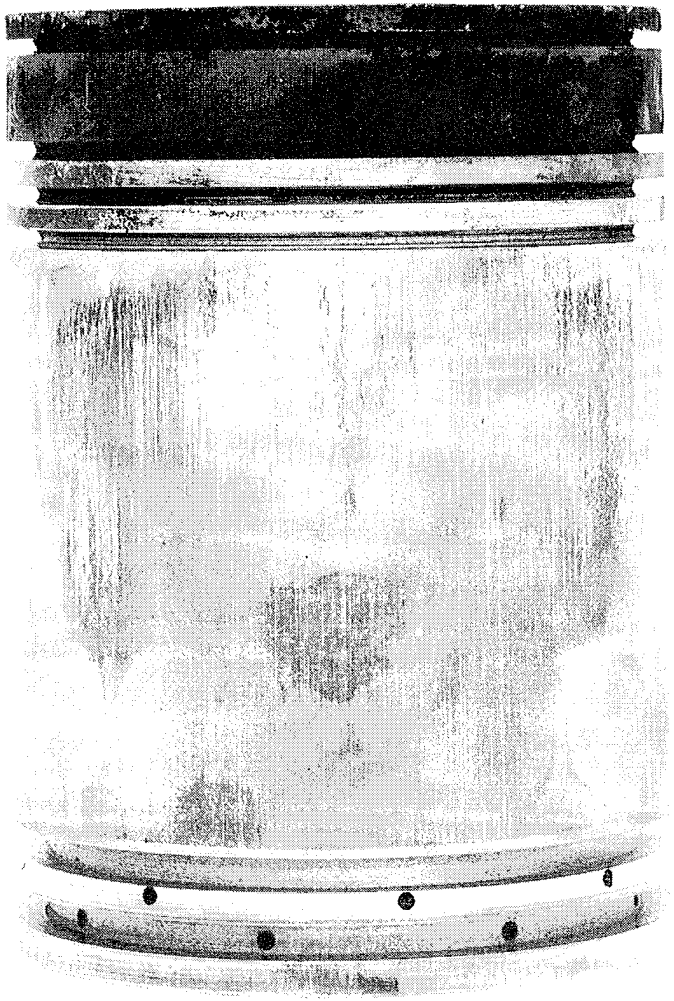
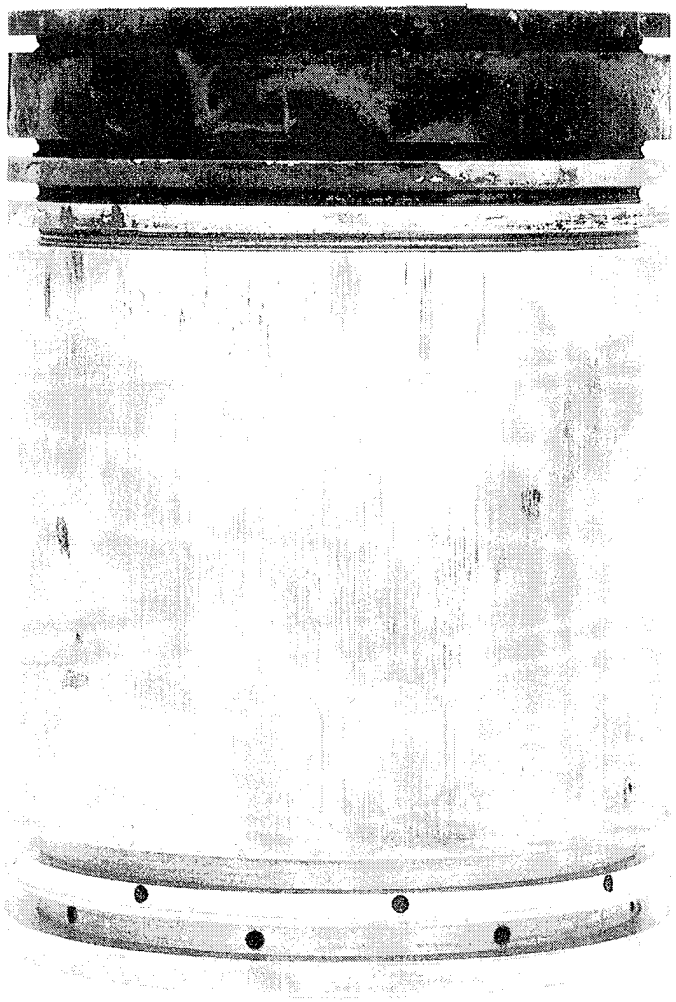
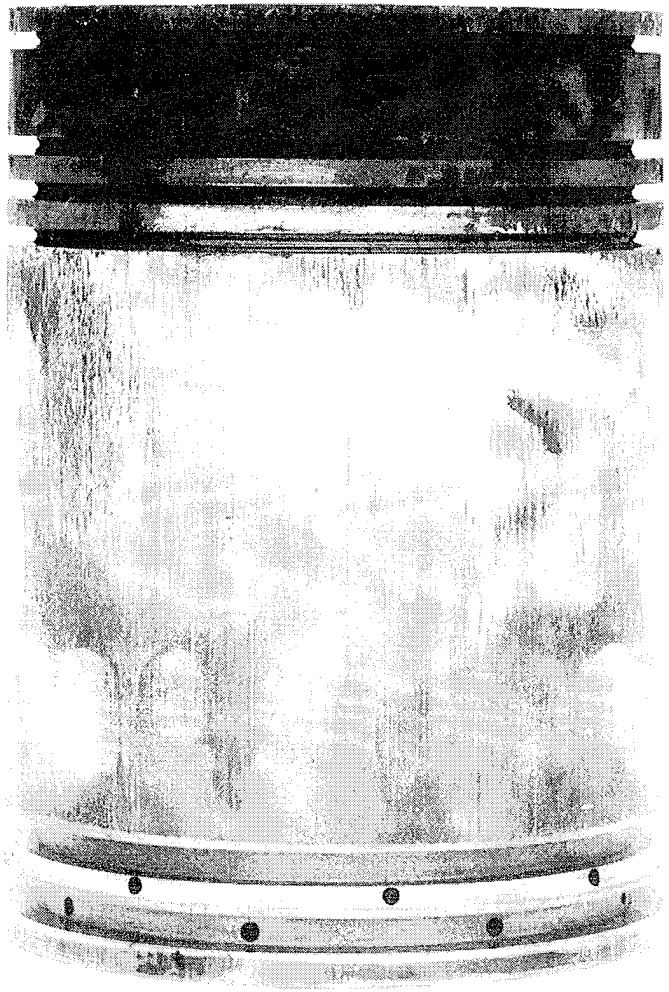
AL19709-F
21.5 HRS.
1-R-T



6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
1-R-AT



6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
2-R-T



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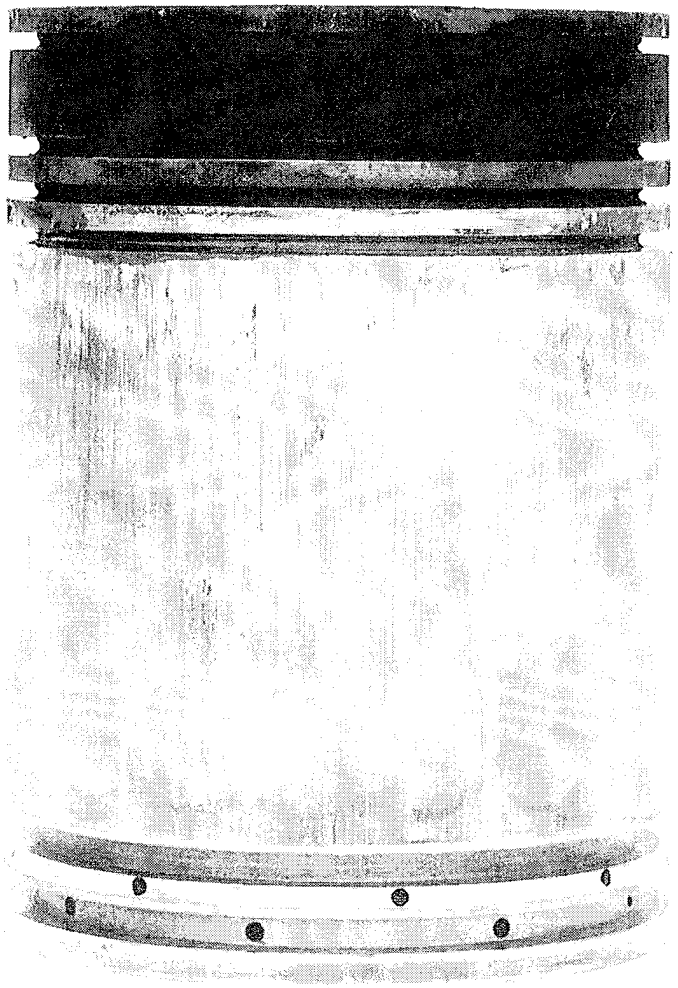
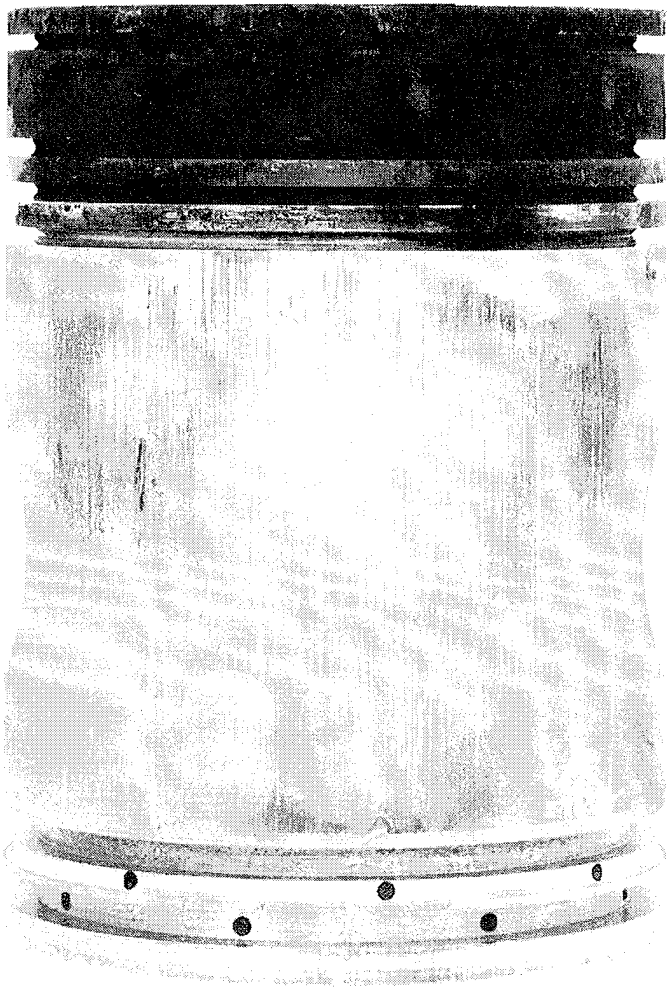
AL19547-L
AL19709-F
21.5 HRS.
2-R-AT



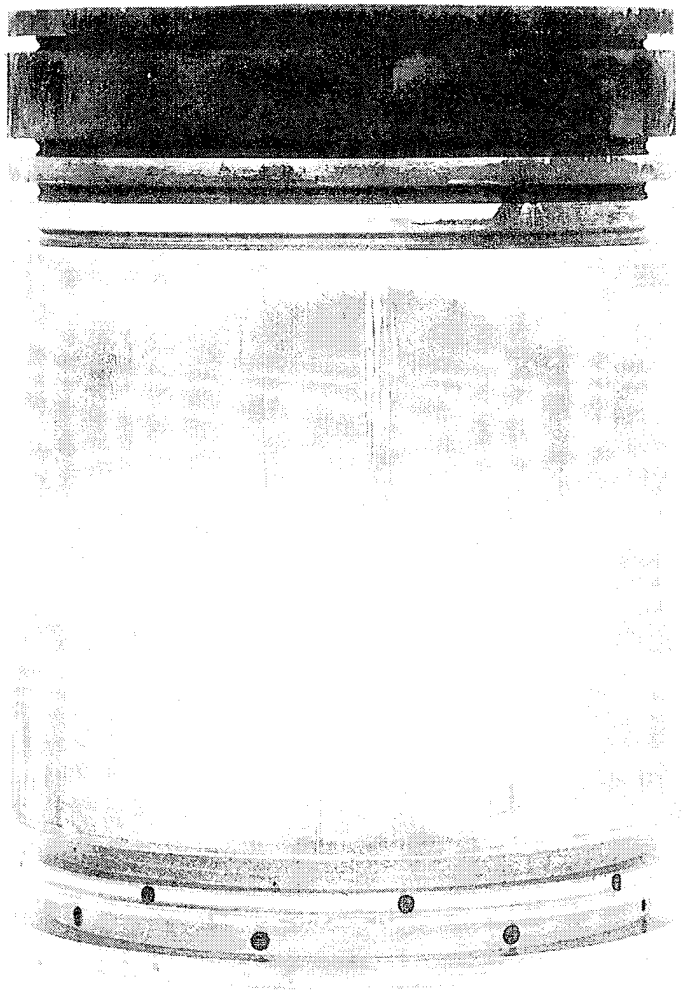
6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
3-R-T

6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
3-R-AT



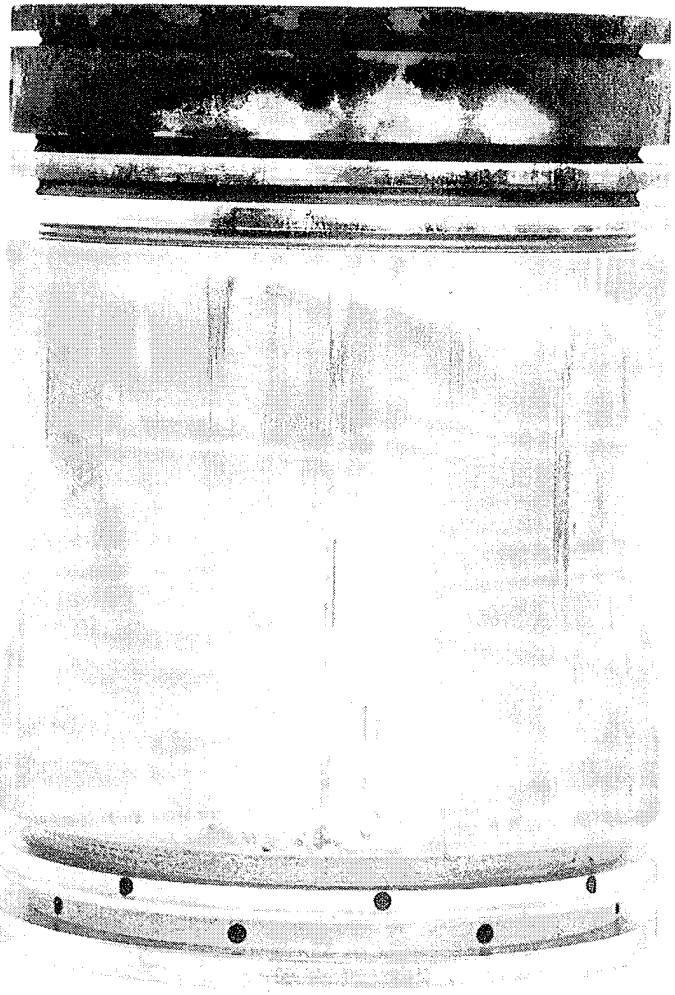
6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
1-L-T

6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
1-L-AT

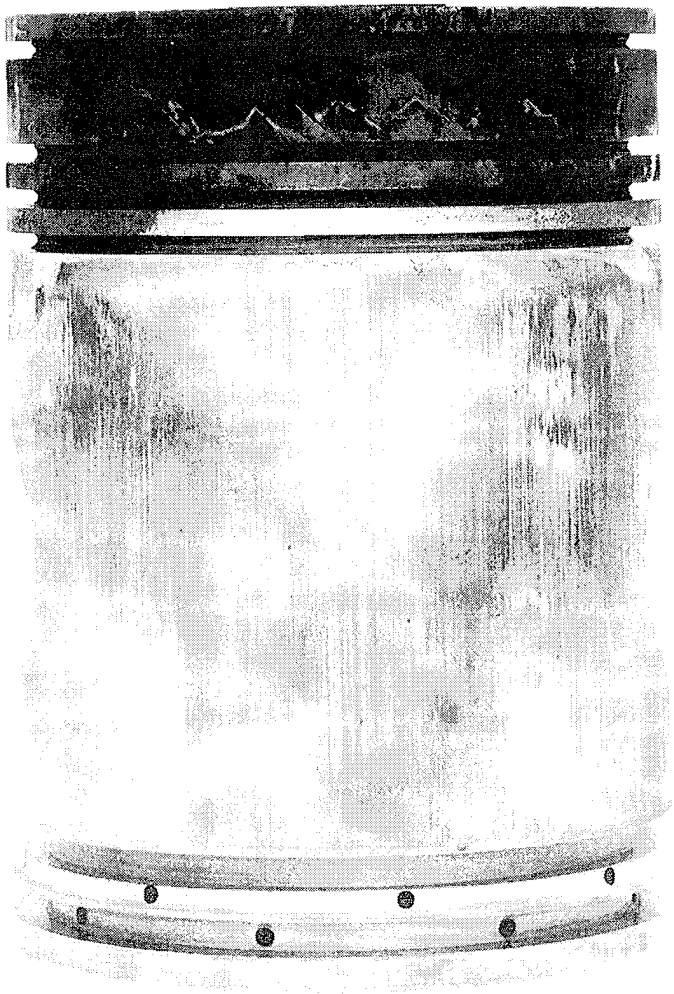


6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
2-L-T

6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
2-L-AT



6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
3-L-T



6V53T 58A
AL19547-L
AL19709-F
21.5 HRS.
3-L-AT

APPENDIX E

Test 6V-53T — 59A

Lubricant "A-2"
AL-20483-L

6V-53T
Test 59A
ENGINE REBUILD MEASUREMENTS
Lubricant: AL-20483-L

	Min		Max		Avg		Specified Limits
	mm	in.	mm	in.	mm	in.	mm (in.) - mm (in.)
CYLINDER BLOCK BORE							
Inside Diameter (Bottom)	110.653	4.3566	110.684	4.3578	110.668	4.3572	110.655 (4.3565) - 110.681 (4.3575) New
							- 110.731 (4.3595) Max
Out-of-Round	0.000	0.0000	0.025	0.0010	0.010	0.0004	
Taper	0.000	0.0000	0.015	0.0006	0.006	0.0002	- 0.038 (0.0015) Max
							- 0.038 (0.0015) Max
CYLINDER LINERS (Installed)							
Inside Diameter	98.431	3.8754	98.459	3.8765	98.446	3.8760	98.430 (3.8752) - 98.468 (3.8767)
Out-of-Round	0.000	0.0000	0.015	0.0006	0.006	0.0002	- 0.038 (0.0015) Max
Taper	0.000	0.0000	0.018	0.0007	0.007	0.0003	- 0.038 (0.0015) Max
Piston Diameter (at Skirt)	98.243	3.8680	98.259	3.8686	98.253	3.8684	98.219 (3.8669) - 98.775 (3.8691)
Piston Skirt-to-Cylinder Liner Clearance	0.173	0.0068	0.211	0.0083	0.193	0.0076	0.155 (0.0061) - 0.249 (0.0098)
COMPRESSION RINGS							
Gap (No. 1, Fire Ring)	0.71	0.028	0.81	0.032	0.75	0.030	0.51 (0.020) - 1.0 (0.040)
Gap (Nos. 2, 3, 4)	0.56	0.022	0.81	0.032	0.70	0.028	0.51 (0.020) - 1.0 (0.040)
RING-TO-GROOVE CLEARANCE							
Top (No. 1, Fire Ring)	0.076	0.0030	0.076	0.0030	0.076	0.0030	0.08 (0.0030) - 0.17 (0.0066)
No. 2, Compression Ring	0.178	0.0070	0.203	0.0080	0.195	0.0077	0.18 (0.0070) - 0.27 (0.0105)
Nos. 3 and 4, Compression Rings	0.127	0.0050	0.203	0.0080	0.148	0.0058	0.13 (0.0050) - 0.22 (0.0085)
OIL CONTROL RINGS (Nos. 5, 6, 7)							
Gap	0.305	0.0120	0.381	0.0150	0.340	0.0134	0.254 (0.0100) - 0.508 (0.020)
Ring-to-Groove Clearance	0.051	0.0020	0.102	0.0040	0.070	0.0028	0.038 (0.0015) - 0.140 (0.0055)
PISTON PIN							
Pin-to-Piston Bushing Clearance	0.069	0.0027	0.079	0.0031	0.076	0.0030	0.064 (0.0025) - 0.864 (0.0034)
Pin-to-Connecting Rod Bushing Clearance	0.030	0.0012	0.038	0.0015	0.036	0.0014	0.025 (0.0010) - 0.048 (0.0019)
Connecting Rod Bearing-to-Journal Clearance	0.041	0.0016	0.076	0.0030	0.060	0.0024	0.028 (0.0011) - 0.104 (0.0041)
Main Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.076 (0.0030) - 0.127 (0.0050)
Camshaft Bearing-to-Journal Clearance	0.000	0.0000	0.000	0.0000	0.000	0.0000	0.114 (0.0045) - 0.152 (0.0060)

Detroit Diesel 6V-53T
Test 59A
FTM-355 TRACKED VEHICLE CYCLE ENDURANCE TEST — OPERATING CONDITIONS SUMMARY
Lubricant: AL-20483-L
Fuel: Reference No. 2 Diesel Fuel

	Maximum Power Mode, 2,800 rpm		Maximum Torque Mode, 2,200 rpm	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	2,802	3	2,201	2
Torque, N-m (lb-ft)	759 (554.3)	3 (1.9)	853 (623.3)	1.20 (2.7)
Fuel Consumption, kg/hr (lb/hr)	51.93 (114.6)	0.300 (0.66)	44.13 (97.4)	0.51 (1.13)
Observed Power, kW (bhp)	221 (295.7)	0.8 (1.0)	195 (261.2)	0.8 (1.1)
BSFC, g/kW-hr (lb/bhp-hr)	0.236 (0.388)	0.0012 (0.002)	0.227 (0.373)	0.0023 (0.004)
Temperatures, °C (°F)				
Exhaust Before Turbo	534 (992)	5.8 (10.4)	534 (993)	12.4 (22.2)
Exhaust After Turbo	387 (728)	83.2 (149.8)	417 (782)	23.7 (42.7)
Water Jacket Inlet	72 (162)	1.4 (2.4)	72 (161)	1.3 (2.4)
Water Jacket Outlet	76 (169)	1.0 (1.8)	76 (169)	0.9 (1.6)
Oil Sump	110 (230)	1.8 (3.2)	104 (220)	0.9 (3.5)
Fuel at Filter	36 (97)	2.0 (3.6)	35 (95)	1.5 (2.8)
Inlet Air	33 (92)	2.3 (4.1)	33 (91)	2.2 (4.0)
Airbox	143 (290)	1.6 (2.9)	112 (233)	2.0 (3.6)
Pressures				
Exhaust Before Turbo, kPa (psi)	91.82 (13)	5.963 (0.9)	60.50 (9)	1.973 (0.3)
Exhaust After Turbo, kPa (in. Hg)	4.94 (1.5)	1.260 (0.4)	2.54 (0.8)	0.387 (0.1)
Compressor Discharge, kPa (psi)	101.60 (15)	2.866 (0.4)	76.84 (11)	2.605 (0.4)
Blower Discharge, kPa (psi)	127.50 (18)	4.196 (0.6)	76.70 (11)	2.609 (0.4)
Oil Gallery, kPa (psi)	280.90 (41)	8.830 (1.3)	252.60 (37)	10.828 (1.6)
Intake Vacuum, kPa (in. H_2O)	29.65 (9)	1.616 (0.5)	17.83 (5)	0.916 (0.3)
Ambient Conditions				
Dry Bulb Temperature, °C (°F)	29 (84)	3.2 (5.8)	28 (83)	2.7 (4.9)
Wet Bulb Temperature, °C (°F)	24 (75)	1.7 (3.0)	23 (74)	1.6 (2.9)
Barometric Pressure, kPa (in. Hg)	98.25 (29.01)	0.291 (0.09)	98.24 (29.01)	0.301 (0.09)

6V-53T
Test 59A
LUBRICANT ANALYSIS
Lubricant: AL-20483-L

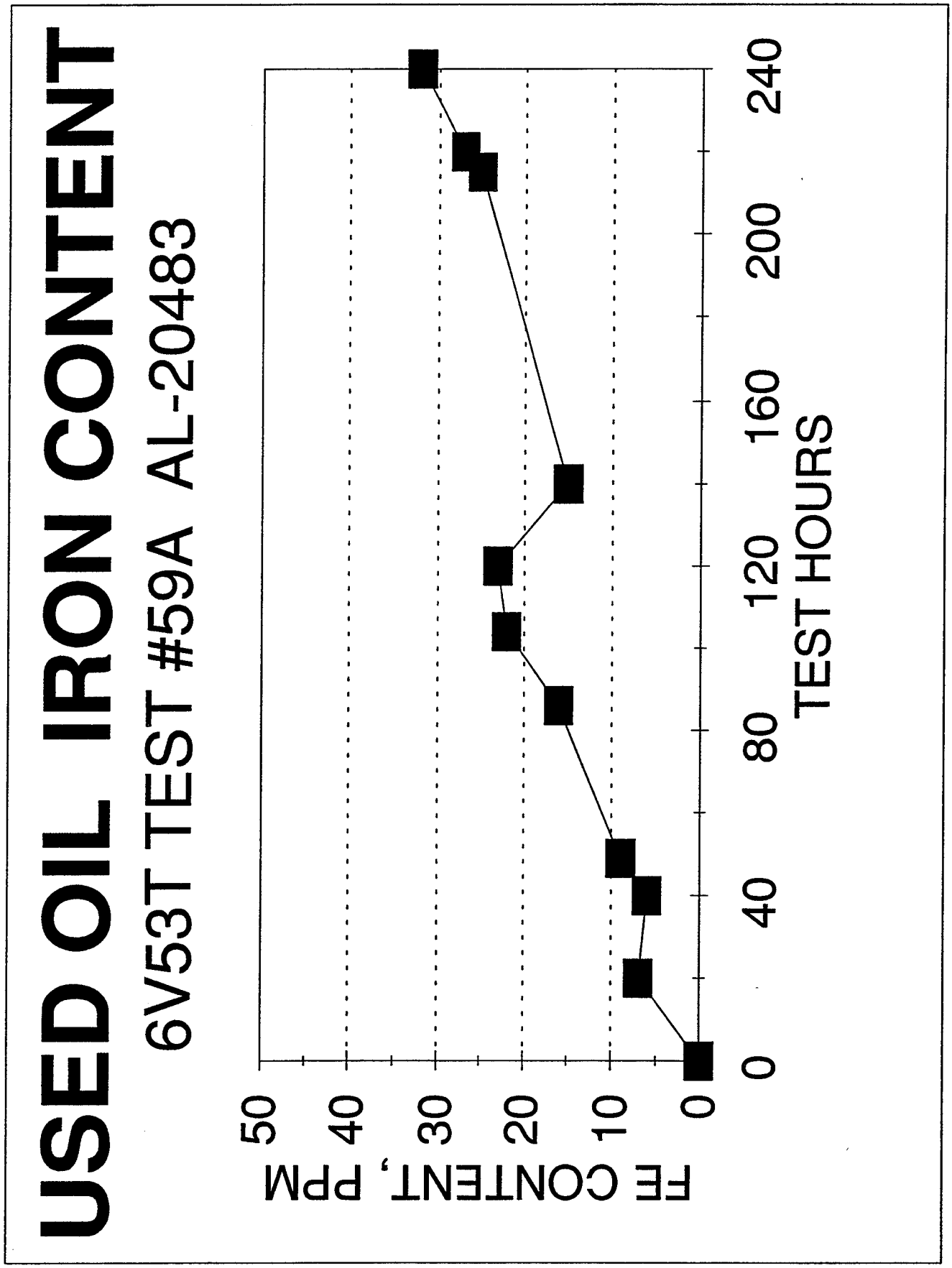
Lubricant Analysis	ASTM Test Method	Test Time, hr 0	120	240
Kinematic Viscosity, cSt, at				
40°C	D 445	52.23	51.78	52.20
100°C	D 445	10.05	9.59	9.78
Total Acid Number, mg KOH/g	D 664	2.3	2.7	2.9
Total Base Number, mg KOH/g	D 664	8.7	3.7	3.9
Pentane B Insolubles, wt%	D 893	NIL	0.005	0.019
Toluene B Insolubles, wt%	D 893	NIL	0.003	0.009
Flash Point, °C	D 92	251	251	249

6V-53T
Test 59A
TOTAL OIL CONSUMPTION AND WEAR METALS BY XRF
Lubricant: AL-20483-L

Test Time, hr	Total Oil Consumed kg	lb	Wear Metals, ppm Fe	Cu
0–36	Fuel Dilution			
40	3.19	7.04	6	1
49	3.19	7.04	9	1
86	16.06	35.40	16	2
104	22.46	49.51	22	2
120	25.68	56.61	23	3
140	32.06	70.69	15	2
160	41.69	91.90	ND*	ND
180	44.72	98.58	ND	ND
200	47.63	105.00	ND	ND
220	56.27	124.05	27	2
240	61.55	135.69	32	2

	kg/hr	lb/hr
Average Oil Consumption Rate	0.256	0.565

* ND = Not Determined


USED OIL IRON CONTENT
6V53T TEST #59A AL-20483
FE CONTENT, PPM
50
40
30
20
10
0
0
40
80
120
160
200
240
TEST HOURS

6V-53T
Test 59A
POST-TEST ENGINE CONDITIONS AND DEPOSITS
Lubricant: AL-20483-L

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Avg
CYLINDER LINER							
Intake Port Plugging							
% Restriction	<1	<1	<1	<1	<1	<1	<1
Liner Scuffing, % Area							
Thrust	0	0	8	48	3	3	10.30
Antithrust	0	1	0	24	25	17	11.20
% Total Area	0	0.5	4	36	14	10	10.75
						Overall:	10.75
					Overall, Five Cylinders (w/o 1R):		5.70
% Area Bore Polished							
Thrust	2	5	8	5	5	1	4.33
Antithrust	9	9	18	11	9	5	10.17
% Avg Area							
Bore Polished	5.5	7	13	8	7	3	7.25
						Overall:	7.25
					Overall, Five Cylinders (w/o 1R):		7.10
Avg Liner Distress	0	0.3	4	45	14	12	12.60
					Overall, Five Cylinders (w/o 1R):		6.10
RINGS							
Ring Face Distress, Demerits							
No. 1	2.00	7.00	20.75	5.25	14.50	5.75	9.21
No. 2	1.25	1.25	5.00	60.00	9.00	6.00	13.75
No. 3	0.25	3.75	1.25	66.25	5.00	7.50	14.00
No. 4	0.25	10.00	3.00	66.25	11.25	12.00	17.13
						Overall, Six Cylinders (Nos. 2 and 3):	13.88
					Overall, Five Cylinders (Nos. 2 and 3) (w/o 1R):		4.03
PISTONS							
Piston Skirt Rating*							
Thrust	8% SC & Lt S	7% SC & Lt S	Lt S	10% SC & Lt S	4% SC & Lt S	Lt S	
Antithrust	Lt S	Lt S	Lt S	5% SC & Lt S	Lt S	Lt S	
Piston WTD Rating**							
Six Cylinders	241.12	281.87	261.24	247.00	256.87	298.50	264.43
Five Cylinders	w/o 1R	--	--	--	--	--	267.92
Ring Sticking***							
No. 1	Sluggish	5% CS	10% CS	F	F	F	
No. 2	F	F	F	F	F	60% CS	
No. 3	F	F	F	F	F	F	
No. 4	F	F	F	F	F	F	
EXHAUST VALVES							
Deposits							
Head+	70 MC, 30 LC	75 MC, 25 LC	80 MC, 20 LC	25 MC, 75 LC	25 MC, 75 LC	65 MC, 35 LC	
Face	← Trace Amount of Carbon and Ash Embedment →						
Tulip++	1.0	1.0	1.0	1.0	--	--	
Stem	← All Stems 5 to 15% #9 Lacquer →						
Surface Conditions							
Freeness in Guide	← All Normal →						
Head	← All Normal →						
Face	← All Normal →						
Seat	← All Normal →						
Stem	← All Normal →						
Tip	← All Normal →						

* Lt = Light, S = Scratches, PM = Plating Melted, N = Normal, SC = Scuffing, and B = Burn

** CRC Weighted Total Deposits (0 = Least, 900 = Most)

*** F = Free, PC = Partially Collapsed, TC = Totally Collapsed, BR = Broken, and CS = Cold Stuck

\+ HC = Hard Carbon, LC = Light Carbon, MC = Medium Carbon — the number indicates percentage

++ The higher the number, the darker the lacquer (0 = Lightest, 9 = Darkest)

6V-53T
Test 59A
LINER AND RING FACE DISTRESS SUMMARY
Lubricant: AL-20483-L

Liner Distress	
Six-Cylinder Avg	12.6
Five-Cylinder Avg (w/o 1R)	6.1
Ring Face Distress, Nos. 2 and 3	
Six-Cylinder Avg	13.88
Five-Cylinder Avg (w/o 1R)	4.03

6V-53T
Test 59A
WEAR MEASUREMENTS
Lubricant: AL-20483-L

Cylinder Liner Bore Diameter Changes

	Cylinder Number											
	1L				2L				3L			
	T-AT*		F-B		T-AT		F-B		T-AT		F-B	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Top	–0.015	–0.0006	–0.030	–0.0012	–0.015	–0.0006	–0.020	–0.0008	–0.013	–0.0005	–0.030	–0.0012
Middle	–0.003	–0.0001	–0.013	–0.0005	–0.013	–0.0005	–0.025	–0.0010	–0.010	–0.0004	–0.010	–0.0004
Bottom	–0.015	–0.0006	–0.018	–0.0007	–0.023	–0.0009	–0.018	–0.0007	–0.015	–0.0006	–0.015	–0.0006

	Cylinder Number											
	1R				2R				3R			
	T-AT		F-B		T-AT		F-B		T-AT		F-B	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Top	0.018	0.0007	–0.013	–0.0005	–0.003	–0.0001	–0.015	–0.0006	0.036	0.0014	–0.018	–0.0007
Middle	–0.008	–0.0003	–0.010	–0.0004	–0.008	–0.0003	–0.003	–0.0001	–0.008	–0.0003	0.000	0.0000
Bottom	–0.023	–0.0009	–0.005	–0.0002	–0.018	–0.0007	–0.005	–0.0002	–0.015	–0.0006	0.005	0.0002

Average Change

	T-AT		F-B	
	mm	in.	mm	in.
Top	0.001	0.0001	–0.021	–0.0008
Middle	–0.008	–0.0003	–0.010	–0.0004
Bottom	–0.018	–0.0007	–0.009	–0.0004

Piston Ring End Gap Change

	Cylinder Number													
	1L		2L		3L		1R		2R		3R		Average Change	
Ring No.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
1	–0.051	–0.0020	–0.051	–0.0020	–0.025	–0.0010	0.051	0.0020	0.000	0.0000	–0.051	–0.0020	–0.021	–0.0008
2	–0.102	–0.0040	0.000	0.0000	0.025	0.0010	0.025	0.0010	–0.051	–0.0020	0.025	0.0010	–0.013	–0.0005
3	0.051	0.0020	0.025	0.0010	0.025	0.0010	0.051	0.0020	0.025	0.0010	0.000	0.0000	0.030	0.0012
4	0.025	0.0010	0.000	0.0000	0.025	0.0010	0.025	0.0010	0.000	0.0000	0.000	0.0000	0.013	0.0005
5	0.102	0.0040	0.127	0.0050	0.178	0.0070	0.102	0.0040	0.102	0.0040	0.102	0.0040	0.119	0.0047
6	0.127	0.0050	0.152	0.0060	0.178	0.0070	0.127	0.0050	0.152	0.0060	0.127	0.0050	0.144	0.0057
7	0.127	0.0050	0.152	0.0060	0.127	0.0050	0.127	0.0050	0.127	0.0050	0.102	0.0040	0.127	0.0050

Overall Average Change

mm	in.
0.0568	0.0022

* T-AT = Thrust-Antithrust, F-B = Front-Back

6V-53T RING FACE DISTRESS
(Six Cylinders)

Sponsor Code: AL-20483-L
Hours: 240

Date: 09-04-93

SwRI Code: BFLRF
Block: 03 Test 59A

Cylinder No.	Ring No.	Extreme (1.00)		Heavy (0.75)		Medium (0.50)		Light (0.25)		Totals	
		% Area	Demerits	% Area	Demerits	% Area	Demerits	% Area	Demerits	% Area	Demerits
1L	1	0	0.00	1	0.75	0	0.00	5	1.25	6	2.00
	2	0	0.00	0	0.00	0	0.00	5	1.25	5	1.25
	3	0	0.00	0	0.00	0	0.00	1	0.25	1	0.25
	4	0	0.00	0	0.00	0	0.00	1	0.25	1	0.25
2L	1	0	0.00	1	0.75	0	0.00	25	6.25	26	7.00
	2	0	0.00	0	0.00	0	0.00	5	1.25	5	1.25
	3	0	0.00	0	0.00	0	0.00	15	3.75	15	3.75
	4	0	0.00	0	0.00	0	0.00	40	10.00	40	10.00
3L	1	0	0.00	1	0.75	0	0.00	80	20.00	81	20.75
	2	0	0.00	0	0.00	0	0.00	20	5.00	20	5.00
	3	0	0.00	0	0.00	0	0.00	5	1.25	5	1.25
	4	0	0.00	0	0.00	0	0.00	12	3.00	12	3.00
1R	1	0	0.00	2	1.50	0	0.00	15	3.75	17	5.25
	2	0	0.00	65	48.75	20	10.00	5	1.25	90	60.00
	3	0	0.00	75	56.25	15	7.50	10	2.50	100	66.25
	4	0	0.00	80	60.00	10	5.00	5	1.25	95	66.25
2R	1	0	0.00	1	0.75	0	0.00	55	13.75	56	14.50
	2	0	0.00	0	0.00	8	4.00	20	5.00	28	9.00
	3	0	0.00	0	0.00	0	0.00	20	5.00	20	5.00
	4	0	0.00	0	0.00	0	0.00	45	11.25	45	11.25
3R	1	0	0.00	2	1.50	2	1.00	13	3.25	17	5.75
	2	0	0.00	3	2.25	0	0.00	15	3.75	18	6.00
	3	0	0.00	2	1.50	6	3.00	12	3.00	20	7.50
	4	0	0.00	0	0.00	4	2.00	40	10.00	44	12.00

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	203	55.25	33.83	9.21
2	166	82.50	27.67	13.75
3	161	84.00	26.83	14.00
4	237	102.75	39.50	17.13
2 & 3	327	166.50	27.25	13.88

6V-53T RING FACE DISTRESS
(Five Cylinders)

Sponsor Code: AL-20483-L
Hours: 240

Date: 09-04-93

SwRI Code: BFLRF
Block: 03 Test 59A

Cylinder 1R Eliminated

Ring No.	Totals		Averages	
	% Area	Demerits	% Area	Demerits
1	186	50.00	37.20	10.00
2	76	22.50	15.20	4.50
3	61	17.75	12.20	3.55
4	142	36.50	28.40	7.30
2 & 3	137	40.25	13.70	4.03

6V-53T
PISTON DEMERIT SUMMARY

Sponsor Code: AL-20483-L
Hours: 240
Date: 09-04-93
SwRI Code: BFLRF
Block: 03 Test 59A

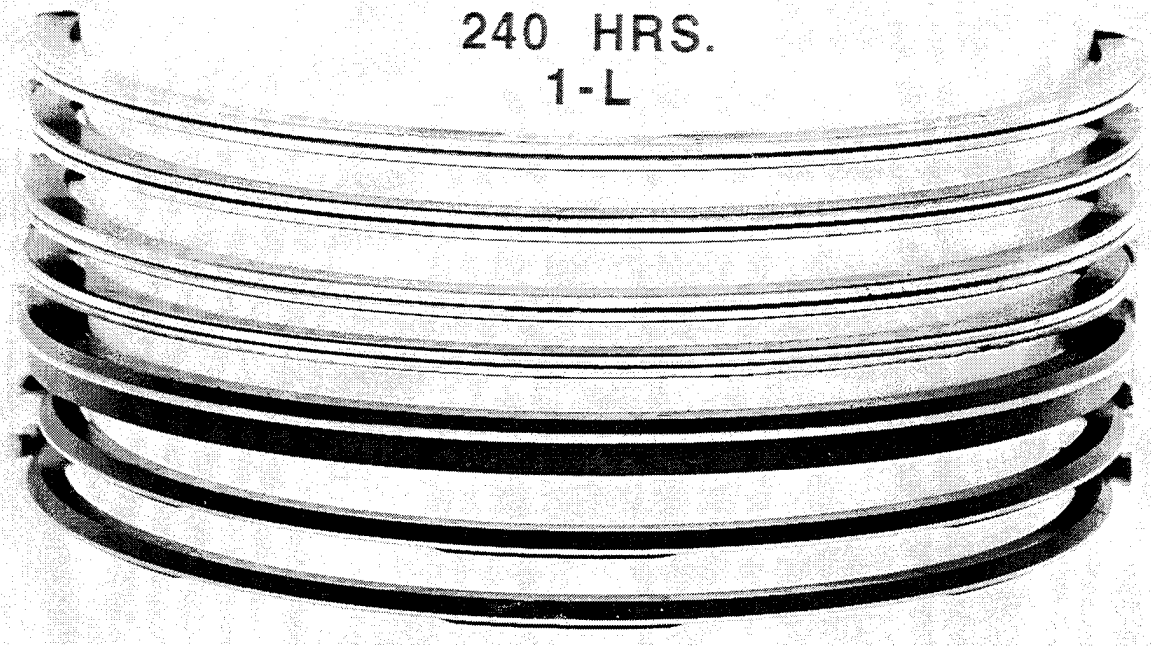
	Piston 1L	Piston 2L	Piston 3L	Piston 1R	Piston 2R	Piston 3R
Carbon (Grooves)	111.25	128.75	105.00	108.75	112.50	136.25
Carbon (Lands)	121.50	148.75	147.50	135.00	141.25	160.50
Lacquer (Grooves)	4.37	3.25	3.12	2.25	2.75	1.50
Lacquer (Lands)	4.00	1.12	5.62	1.00	0.37	0.25
Total Demerits	241.12	281.87	261.24	247.00	256.87	298.50

Average of All Six Pistons

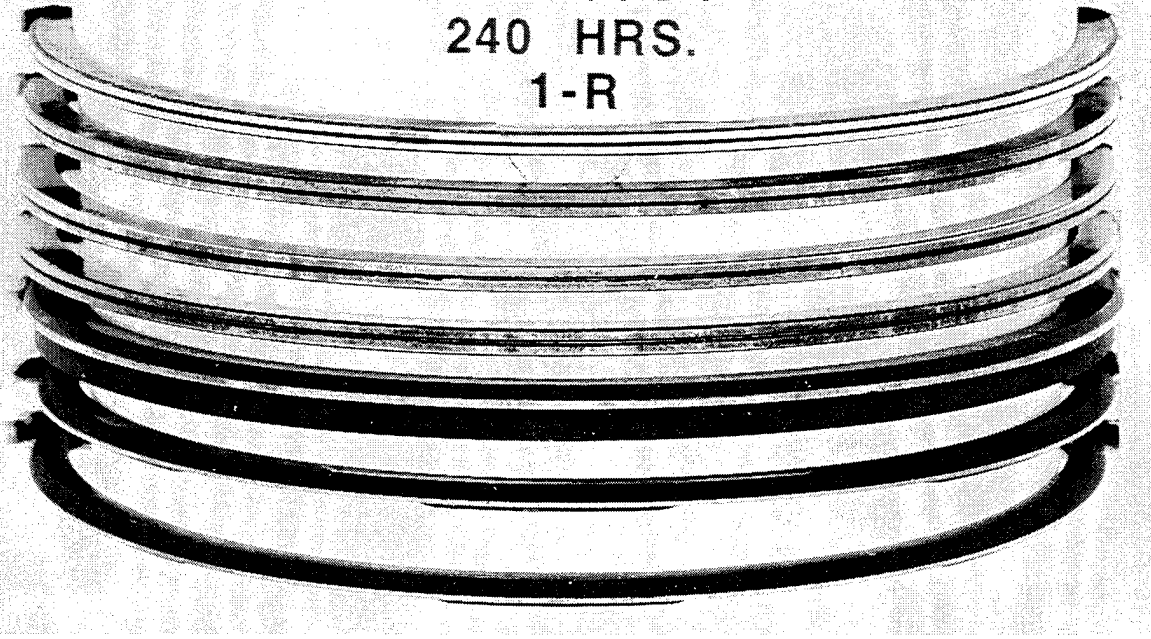
Demerits Due to Carbon	1,557.0
Demerits Due to Lacquer	29.60
Total Demerits	1,586.6
Average Demerits	264.43
Average Piston	3L
Worst Piston	3R

Average of Five Pistons	Excluding 1R
Demerits Due to Carbon	1,313.25
Demerits Due to Lacquer	26.35
Total Demerits	1,339.6
Average Demerits	267.92
Average Piston	3L
Worst Piston	3R

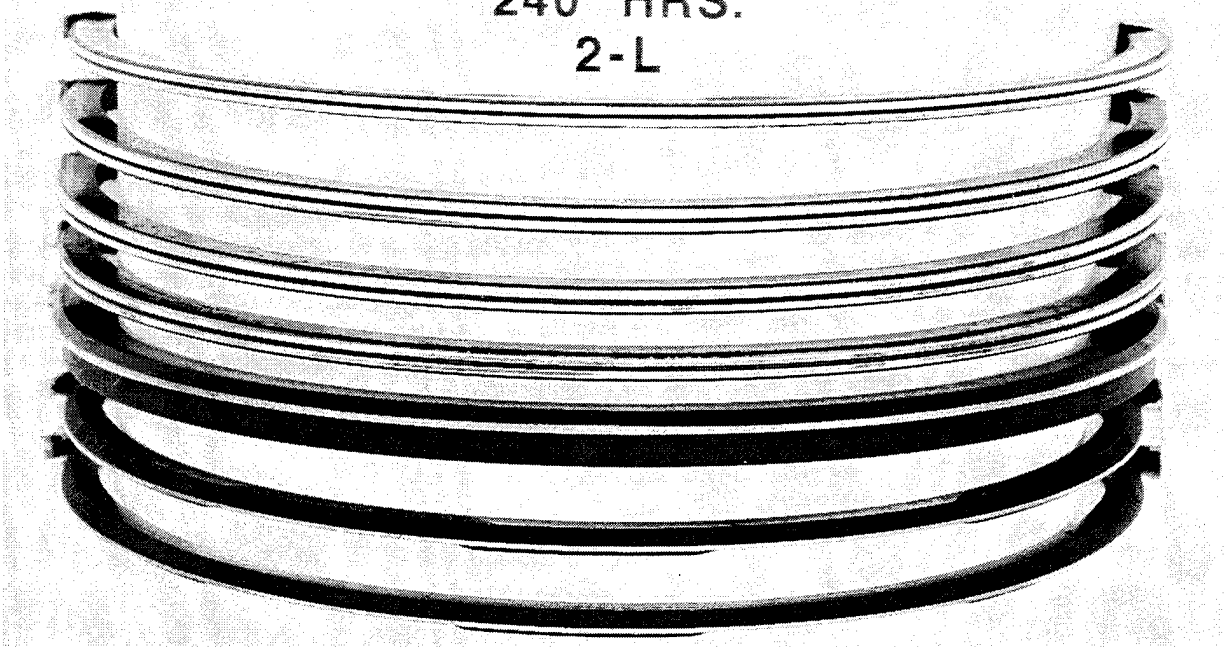
6V53T 59
AL20483-L
AL-20332-F
240 HRS.
1-L



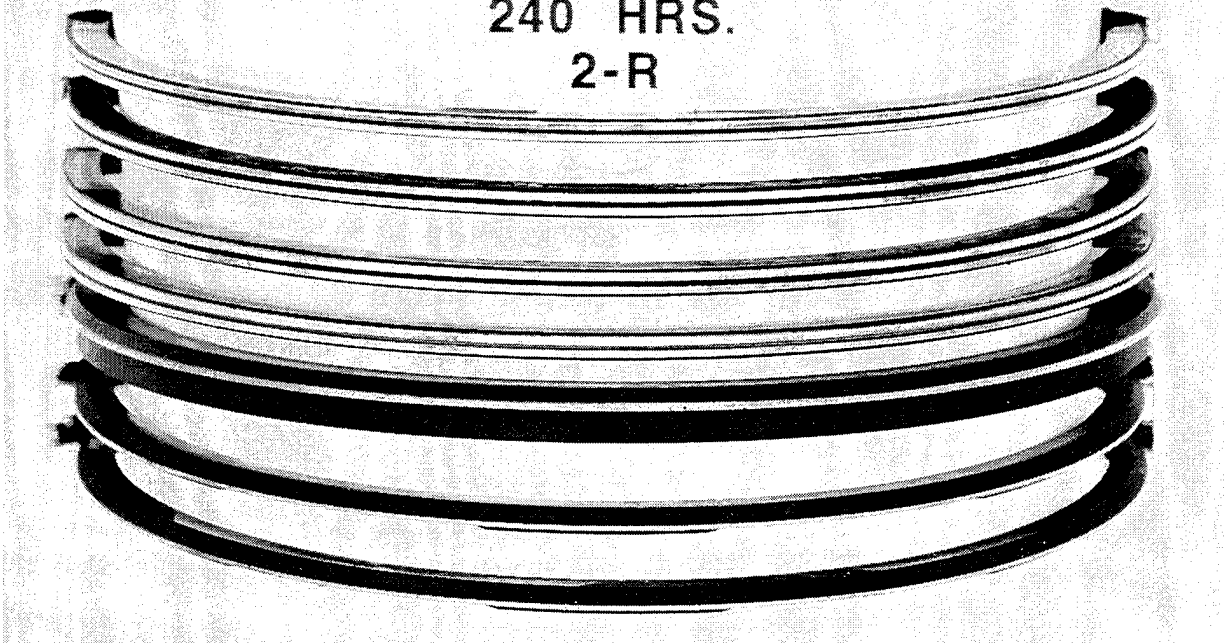
6V53T 59
AL20483-L
AL-20332-F
240 HRS.
1-R



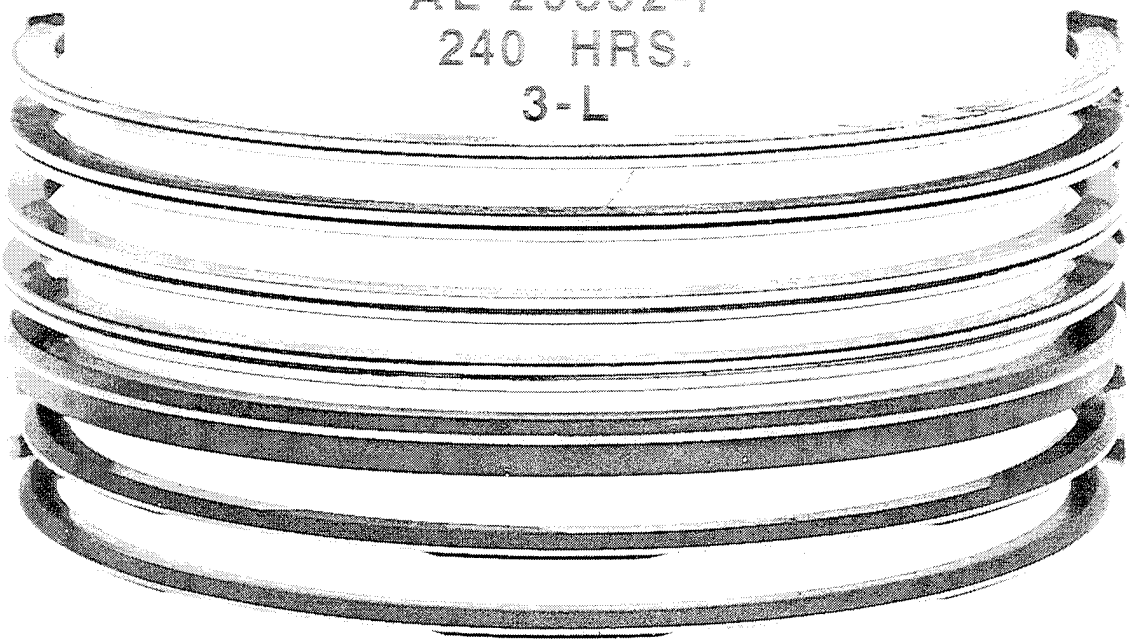
6V53T 59
AL20483-L
AL-20332-F
240 HRS.
2-L



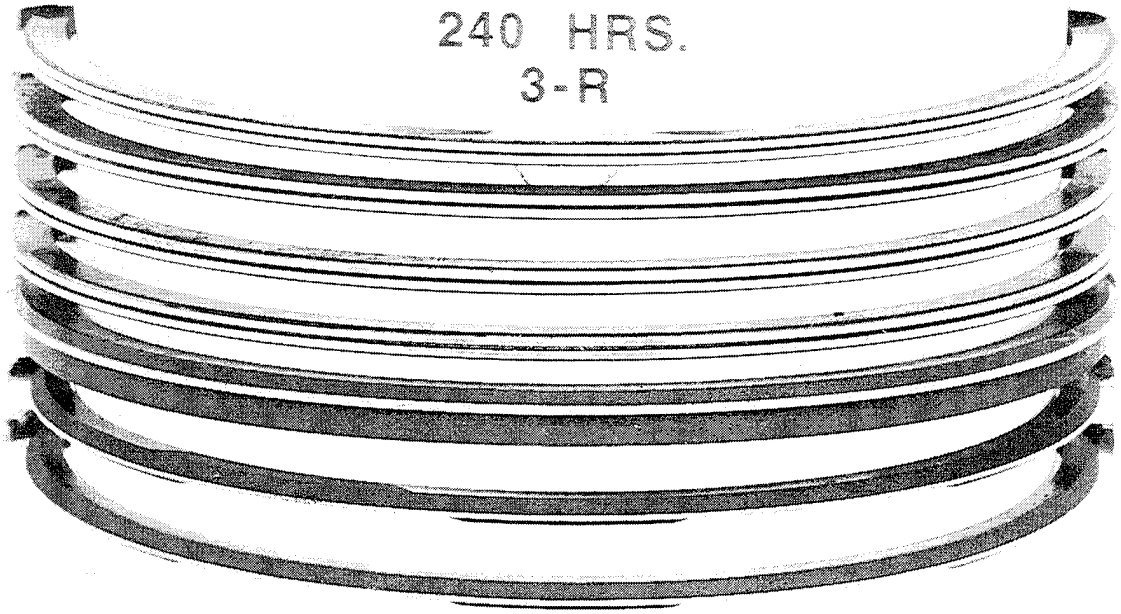
6V53T 59
AL20483-L
AL-20332-F
240 HRS.
2-R

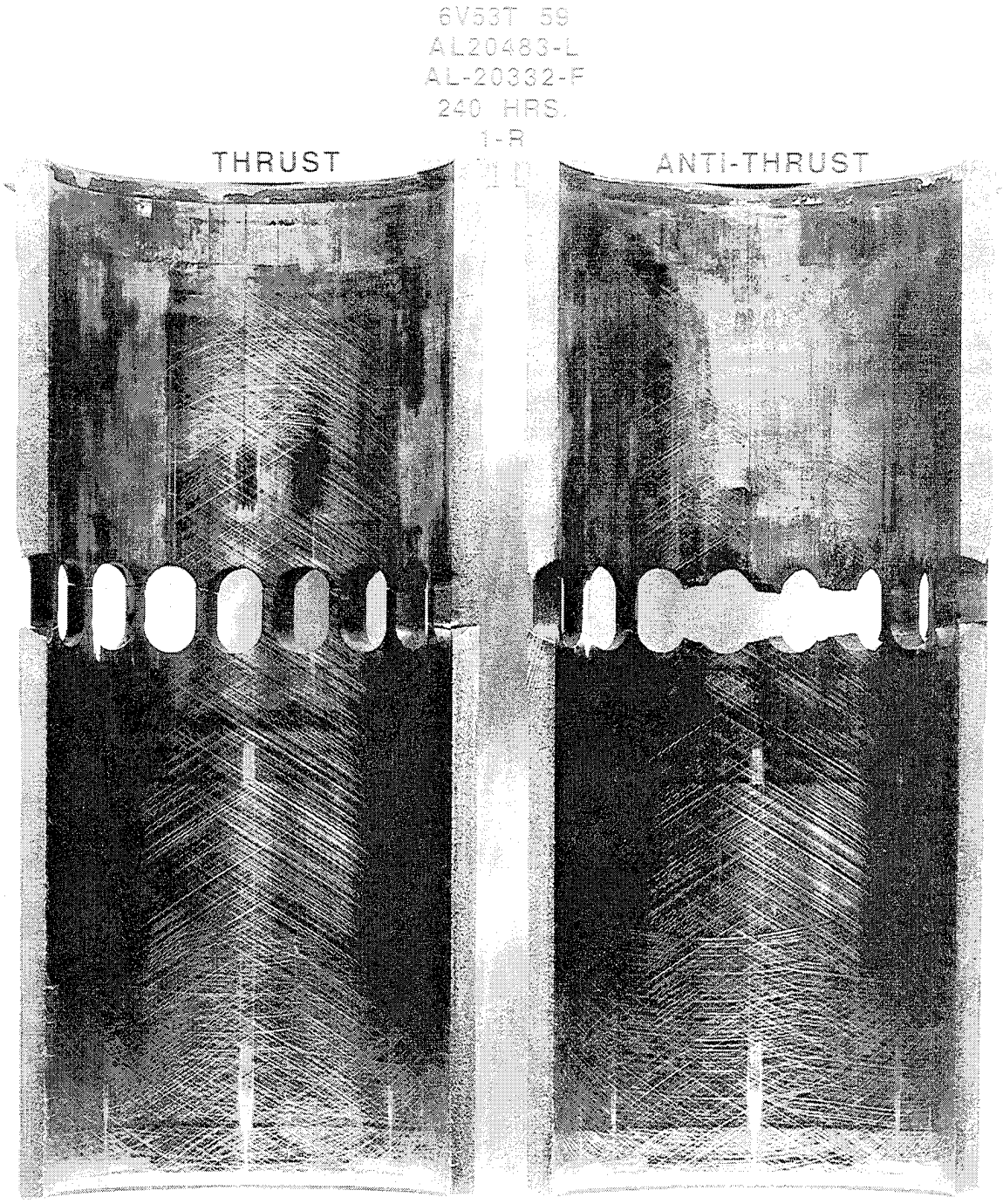


6V53T 59
AL20483-L
AL-20332-F
240 HRS.
3-L



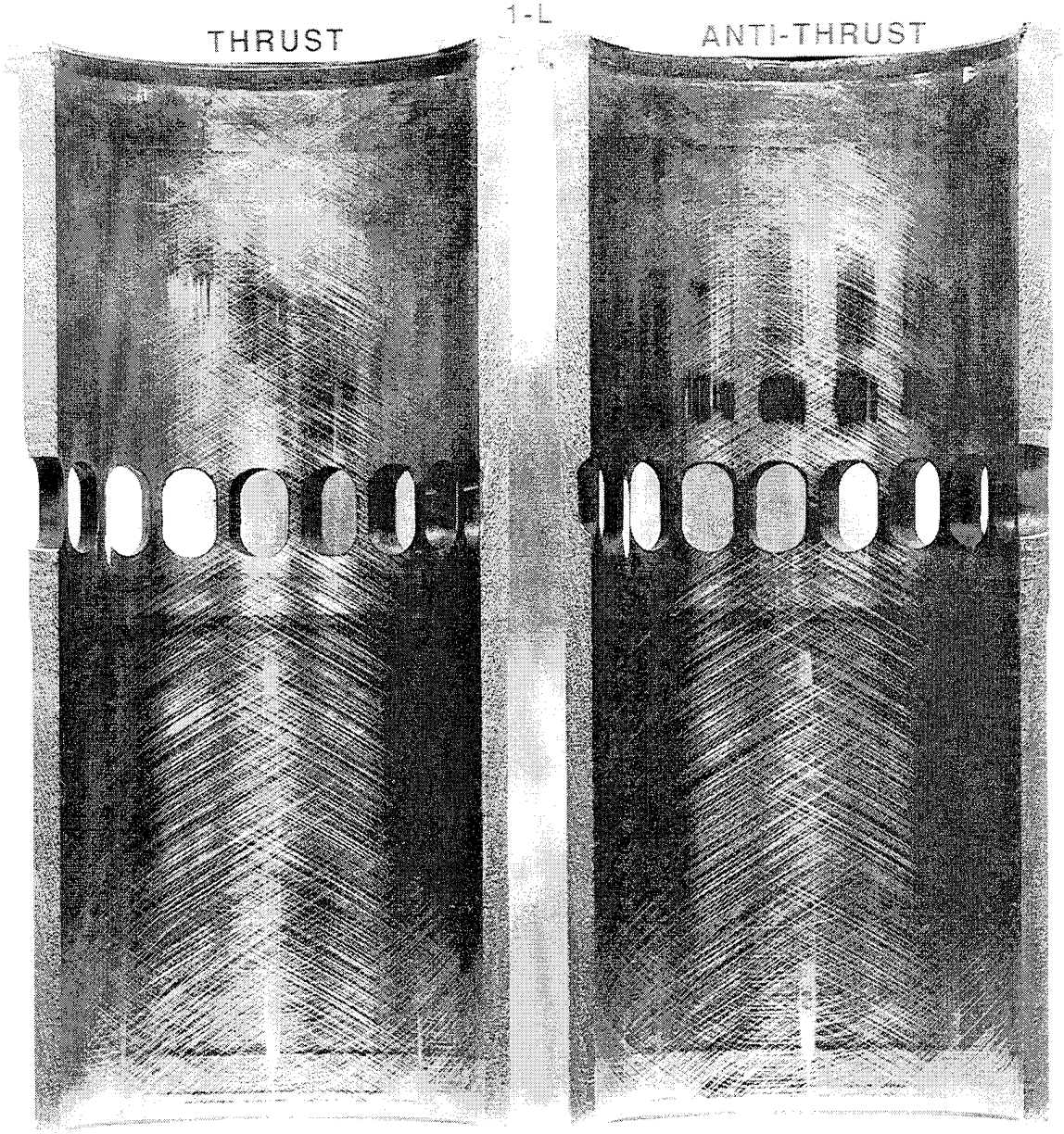
6V53T 59
AL20483-L
AL-20332-F
240 HRS.
3-R



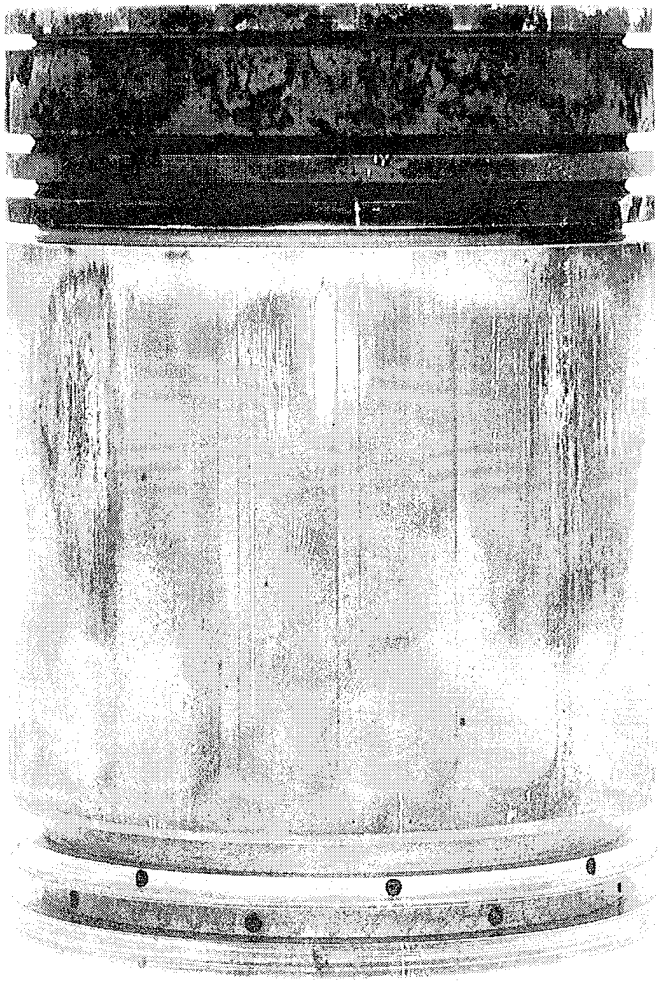


(The bridge area damage was not test related.)

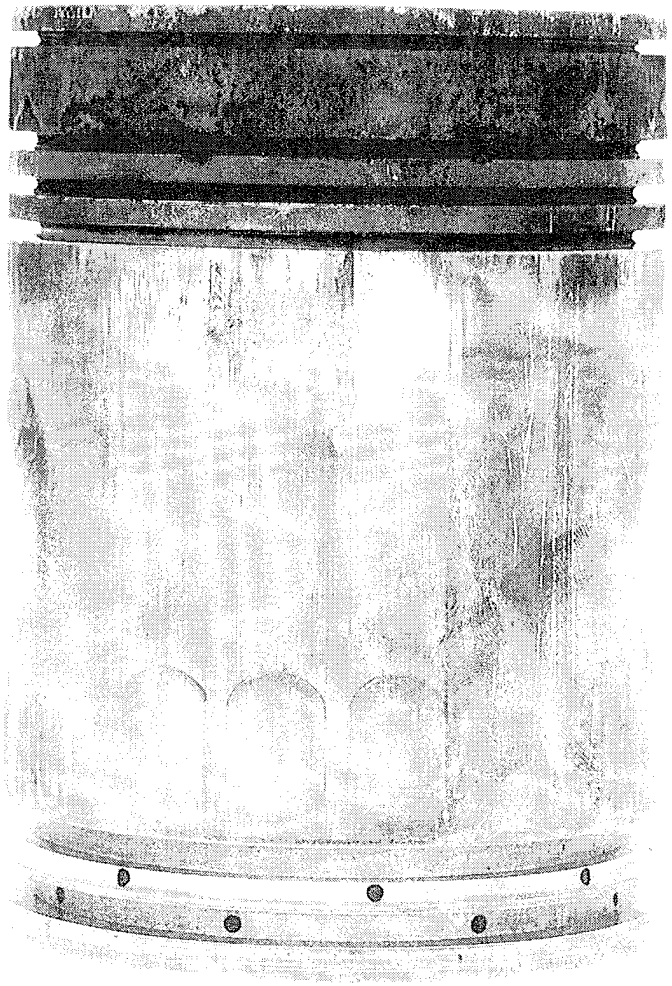
6V53T 59
AL20483-L
AL-20332-F
240 HRS.
1-L



6V53T 59
AL20483-L
AL-20332-F
240 HRS.
1-R-T



6V53T 59
AL20483-L
AL-20332-F
240 HRS.
1-R-AT



APPENDIX F

Report on Allison Hydraulic Transmission Fluid, Type C-4 Graphite Clutch Friction Test

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

BELVOIR FUELS AND LUBRICANTS RESEARCH FACILITY

AL-19660-L
Test Number: C7-4-181

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

July 14, 1991

C-4 Heavy Duty Transmission Fluid Specification

Allison Transmission Division General Motors

VIII Graphite Clutch Friction Test

Test Laboratory: SwRI
Lab Fluid Code: ---
Test Number: C7-4-181
Sponsor Fluid Code: AL-19660-L
Fric. Plate Batch: 32
Completion Date: 07/14/91
Steel Plate Batch: Jun 6 90

Chemical Analysis

	Method	Results	Units	MIN	MAX
Barium	ICP	---	ppm		
Boron	ICP	---	ppm		
Calcium	ICP	---	ppm		
Magnesium	ICP	---	ppm		
Phosphorus	ICP	---	ppm		
Sodium	ICP	---	ppm		
Zinc	ICP	---	ppm		
Viscosity at 40°C	D445	---	cSt		
Viscosity at 100°C	D445	---	cSt		

Friction Characteristics

	Limits		Results				
	Max	Max Chg.	1,500 N	5,500 N	% Change	Pass	Fail
Slip Time Maximum	0.76	N/A	0.660	0.700	6.061	X	
0.2 seconds Dynamic Coeff.	N/A	N/A	0.106	0.096	-9.434		
Mid-Point Fric. Coeff. Min.	0.097	N/A	0.109	0.106	-2.752	X	
Static Friction Coeff.	N/A	N/A	0.146	0.142	-2.740		
Low Speed Peak Fric. Coeff.	N/A	N/A	0.155	0.153	-1.290		
.25 Second Low Speed Coeff.	N/A	N/A	0.150	0.146	-2.667		

Clutch Wear Data

	Maximum Wear		Average Wear		Pass	Fail
	Limits	Results	Limits	Results		
Steel Plates (2)	N/A	0.0060	N/A	0.0021		
Clutch Plate (1)	N/A	0.0770	N/A	0.0645		
Pack Clearance	N/A	0.4062	N/A	0.5080		

Reference Tests

Test Number	Test Date	Test Fluid
C7-0-143	04/21/91	DDA-PASS-L
C7-0-154	05/18/91	DDA-PASS-L
C7-0-165	06/01/91	DDA-PASS-L
C7-0-177	07/06/91	DDA-PASS-L

	New	EOT
Viscosity @ 40°C	---	39.68
Viscosity @ 100°C	---	7.63
Iron Content	---	33

Name: Raymond D. Townsend, Jr.
Title: Group Leader

Signature: Raymond D. Townsend, Jr.
Date: July 14, 1991

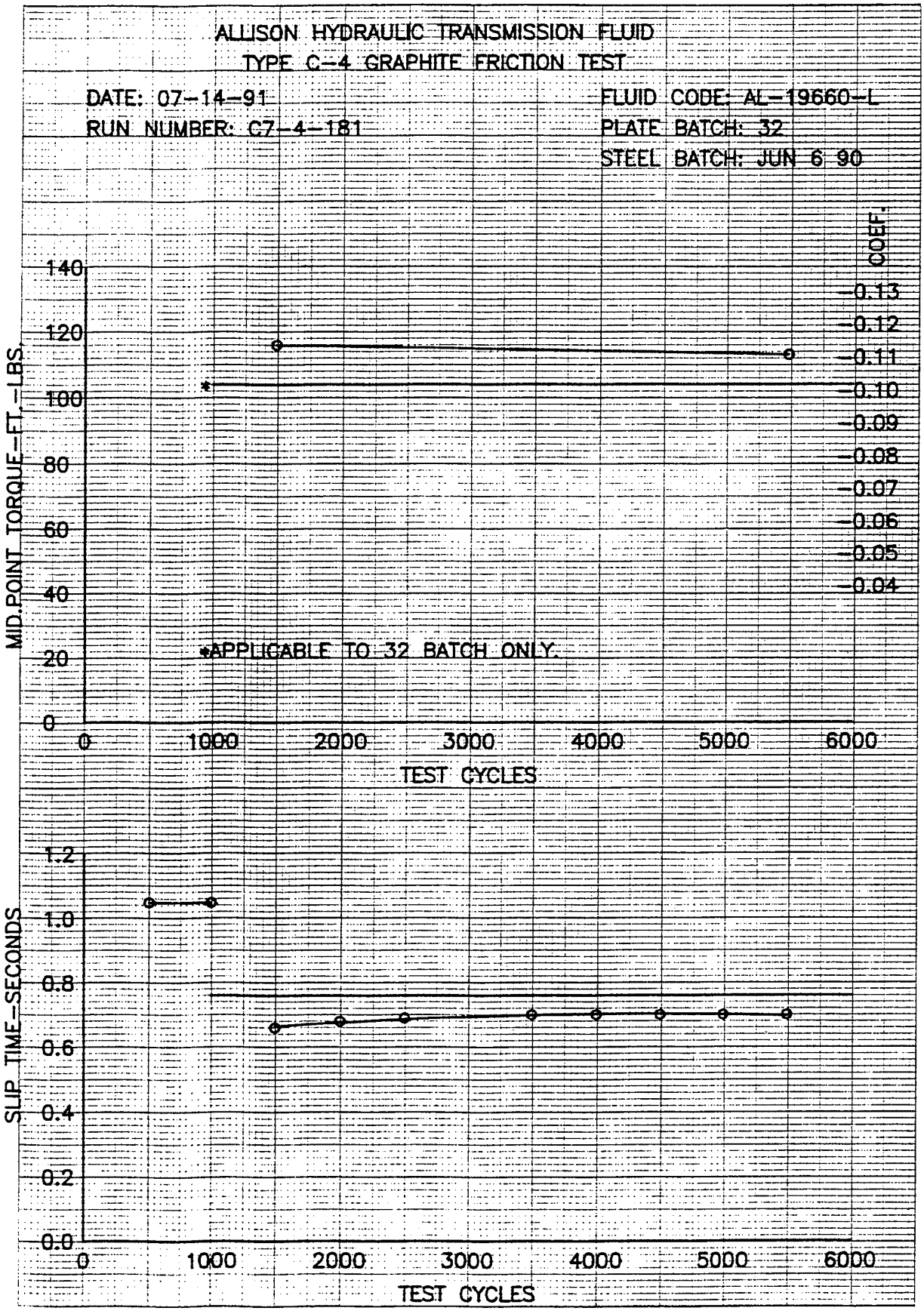
ALLISON C-4 GRAPHITE FRICTION TEST

Sponsor Fluid Code: AL-19660-L
Lab Fluid Code: ---
Completion Date: 07/14/91

Test Number: C7-4-181
Fric. Plate Batch: 32
Steel Plate Batch: Jun 6 90

PLATES		THICKNESS, mm						
CLOCKWISE	LOCATION OF TOOTH	NEAR INNER DIAMETER BEFORE	AFTER	CHANGE	NEAR OUTER DIAMETER BEFORE	AFTER	CHANGE	AVERAGE OVERALL CHANGE
				FRICTION				
2	TOP	2.235	2.180	0.055	2.240	2.176	0.064	
CLOCKWISE	120°	2.240	2.179	0.061	2.240	2.167	0.073	
	240°	2.237	2.180	0.057	2.240	2.163	0.077	
	AVERAGE			0.058			0.071	0.0645
				STEEL SEPARATORS				
1	TOP	1.741	1.741	0.000	1.741	1.740	0.001	
CLOCKWISE	120°	1.746	1.746	0.000	1.748	1.748	0.000	
	240°	1.745	1.741	0.004	1.746	1.744	0.002	
	AVERAGE			0.001			0.001	0.0010
3	TOP	1.783	1.779	0.004	1.783	1.780	0.003	
CLOCKWISE	120°	1.770	1.768	0.002	1.772	1.766	0.006	
	240°	1.772	1.771	0.001	1.774	1.772	0.002	
	AVERAGE			0.002			0.004	0.0030

PLATE CONDITION AT E.O.T.: (Anything Unusual) None


ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST
DATE: 07-14-91
RUN NUMBER: C7-4-181
FLUID CODE: AL-19660-L
PLATE BATCH: 32
STEEL BATCH: JUN 6 90
COEF.
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
MID.POINT TORQUE-FT.-LBS.
140
120
100
80
60
40
20
0
*APPLICABLE TO 32 BATCH ONLY.
0
1000
2000
3000
4000
5000
6000
TEST CYCLES
SLIP TIME-SECONDS
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
5000
6000
TEST CYCLES

APPENDIX G

Report on Allison Hydraulic Transmission Fluid, Type C-4 Paper Clutch Friction Test

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted for

BELVOIR FUELS AND LUBRICANTS RESEARCH FACILITY

AL-19660-L
Run Number: C2-8-558

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

March 3, 1992

IX. Paper Clutch Friction Test

Test Laboratory: SwRI
Lab Fluid Code: LO-60264
Test Number: C2-8-558
Sponsor Fluid Code: AL-19660-L
Fric. Plate Batch: 2b
Completion Date: 03/03/92
Steel Plate Batch: 05-31-84

Chemical Analysis

	Method	Results	Units	MIN	MAX
Barium	ICP	---	ppm		
Boron	ICP	---	ppm		
Calcium	ICP	---	ppm		
Magnesium	ICP	---	ppm		
Phosphorus	ICP	---	ppm		
Sodium	ICP	---	ppm		
Zinc	ICP	---	ppm		
Viscosity at 40°C	D445	---	cSt		
Viscosity at 100°C	D445	---	cSt		

Friction Characteristics

	Limits		Results				
	<=5,000N	>5,000N	<=5,000N	>5,000N	10,000N	Pass	Fail
Slip Time Maximum	0.69	0.58	0.610	0.500	0.500	X	
Mid-Point Fric. Coeff Min	0.075	0.080	0.079	0.104	0.106	X	
Static Friction Coeff.	N/A	N/A	0.141	0.137	0.137		
Low Speed Peak Fric. Coeff.	N/A	N/A	0.147	0.145	0.145		
.25 Second Low Speed Coeff.	N/A	N/A	0.137	0.136	0.136		

Clutch Wear Data

	Maximum Wear		Average Wear			
	Limits	Results	Limits	Results	Pass	Fail
Steel Plates (4)	N/A	0.0130	N/A	0.0037		
Clutch Plate (2)	N/A	0.0870	N/A	0.0701		
Pack Clearance	N/A	0.8890	N/A	1.1684		

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-516	11/17/91	DDA-PASS-L
C2-0-527	01/01/92	DDA-PASS-L
C2-0-538	01/24/92	DDA-PASS-L
C2-0-550	02/17/92	DDA-PASS-L

	New	EOT
Viscosity @ 40°C	---	---
Viscosity @ 100°C	---	---
Iron Content	---	---

Name: Raymond D. Townsend, Jr.
Title: Group Leader
Signature: Raymond D. Townsend
Date: March 3, 1992

ALLISON C-4 PAPER FRICTION TEST

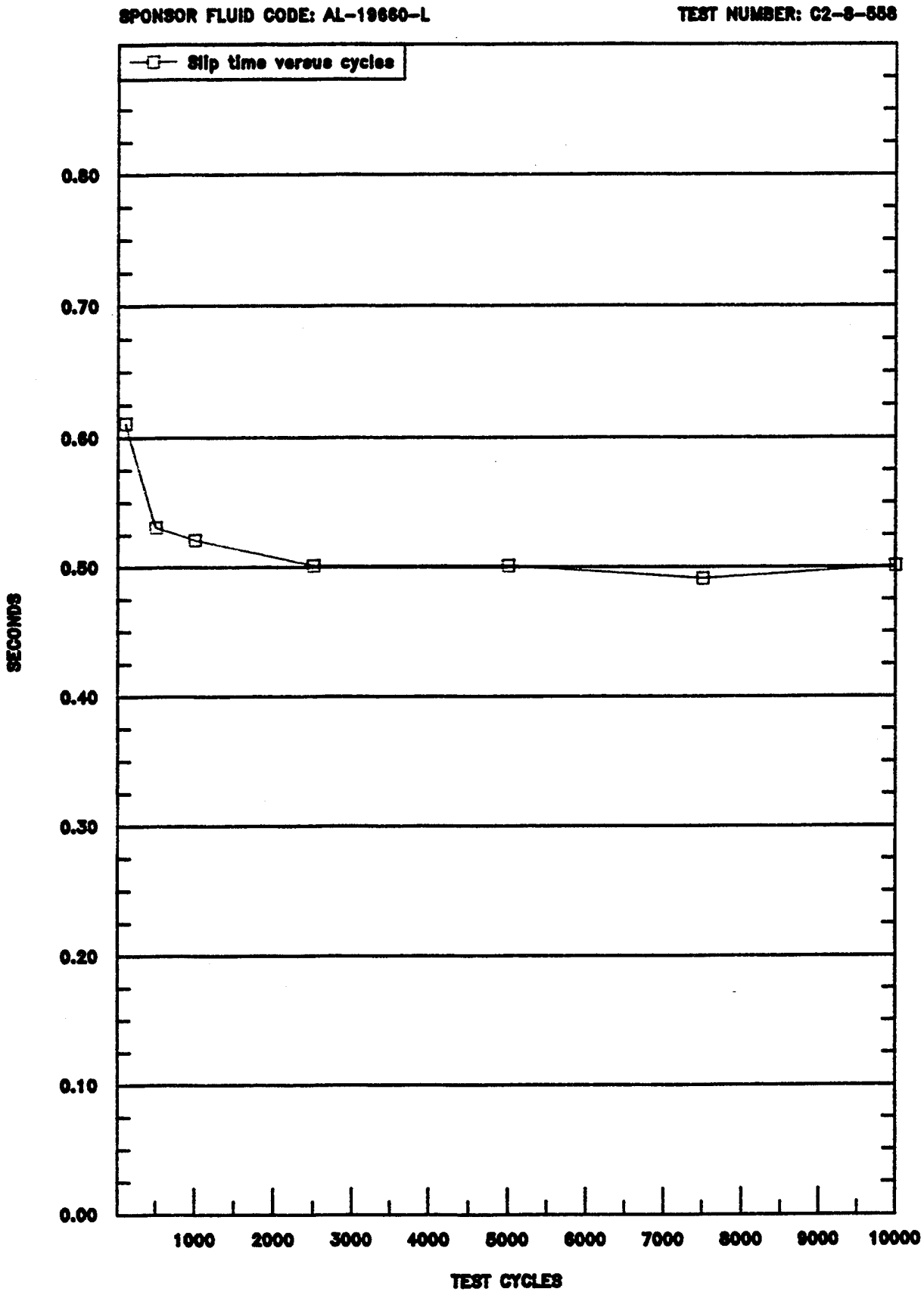
Sponsor Fluid Code: AL-19660-L
Lab Fluid Code: LO-60264
Completion Date: 03/03/92

Test Number: C2-8-558
Fric. Plate Batch: 2b
Steel Plate Batch: 05-31-84

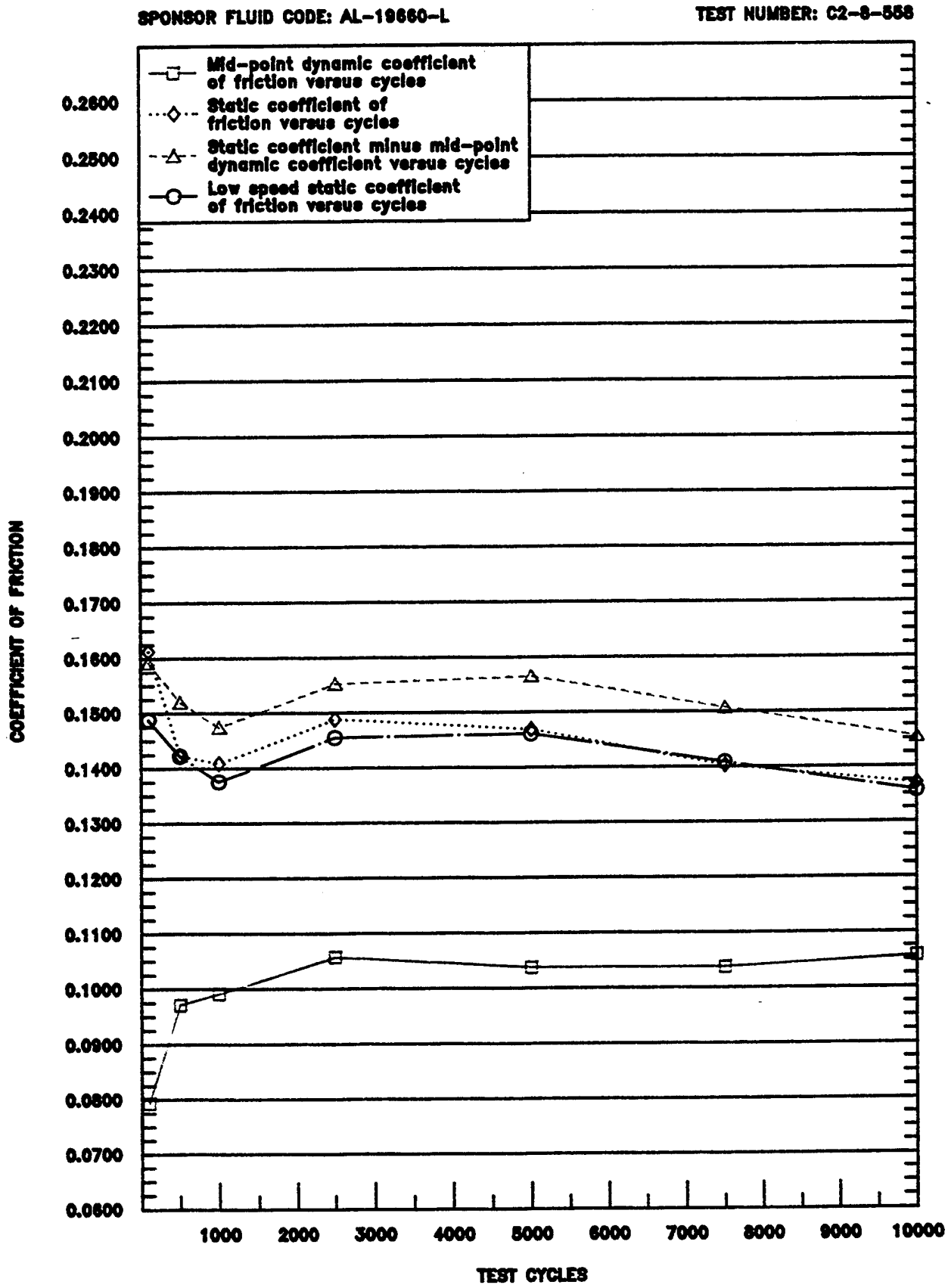
PLATES		THICKNESS, mm						
CLOCKWISE	LOCATION OF TOOTH	NEAR INNER DIAMETER BEFORE	AFTER	CHANGE	NEAR OUTER DIAMETER BEFORE	AFTER	CHANGE	AVERAGE OVERALL CHANGE
FRICTION								
2	TOP	2.057	1.986	0.071	2.062	1.986	0.076	
CLOCKWISE	120°	2.035	1.971	0.064	2.040	1.953	0.087	
	240°	2.040	1.969	0.071	2.040	1.974	0.066	
	AVERAGE			0.069			0.076	0.0725
5	TOP	2.047	1.976	0.071	2.042	1.971	0.071	
CLOCKWISE	120°	2.040	1.971	0.069	2.052	1.979	0.073	
	240°	2.050	1.986	0.064	2.042	1.984	0.058	
	AVERAGE			0.068			0.067	0.0675
STEEL SEPARATORS								
1	TOP	1.730	1.720	0.010	1.730	1.725	0.005	
CLOCKWISE	120°	1.720	1.720	0.000	1.725	1.717	0.008	
	240°	1.730	1.722	0.008	1.735	1.722	0.013	
	AVERAGE			0.006			0.009	0.0075
3	TOP	1.722	1.720	0.002	1.720	1.717	0.003	
CLOCKWISE	120°	1.725	1.725	0.000	1.722	1.722	0.000	
	240°	1.722	1.722	0.000	1.725	1.720	0.005	
	AVERAGE			0.001			0.003	0.0020
4	TOP	1.730	1.727	0.003	1.732	1.727	0.005	
CLOCKWISE	120°	1.735	1.735	0.000	1.737	1.732	0.005	
	240°	1.735	1.727	0.008	1.735	1.727	0.008	
	AVERAGE			0.004			0.006	0.0050
6	TOP	1.727	1.725	0.002	1.727	1.725	0.002	
CLOCKWISE	120°	1.727	1.727	0.000	1.727	1.725	0.002	
	240°	1.725	1.725	0.000	1.725	1.725	0.000	
	AVERAGE			0.001			0.001	0.0010

PLATE CONDITION AT E.O.T.: (Anything Unusual) **None**

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST



ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST



APPENDIX H

Report on Caterpillar TO-4 Friction Properties, VC-70 Sequence 1220

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70 SEQUENCE 1220

Conducted for

BELVOIR FUELS AND LUBRICANTS RESEARCH FACILITY

AL-19660-L
Test Number: VC70-A-1-J

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

March 23, 1992

SUMMARY SHEET

Company: Belvoir Fuels and Lubricants Research Facility

Test start date: March 20, 1992
End of test date: March 23, 1992
Oil: AL-19660-L

SEQUENCE #	1219	1220	1221	1222	1223	1224	FRICTION RETENTION
DYNAMIC COEFFICIENT Vs. CYCLE:	____	FAIL	____	____	____	____	____
DYNAMIC COEFFICIENT Vs. LOAD:	____	PASS	____	____	____	____	N/A
DYNAMIC COEFFICIENT Vs. SPEED:	____	PASS	____	____	____	____	N/A
ENERGY LIMIT:	____	PASS	____	____	____	____	N/A
STATIC COEFFICIENT Vs. CYCLE:	N/A	N/A	N/A	N/A	N/A	N/A	____
STATIC COEFFICIENT Vs. LOAD:	____	PASS	____	____	____	____	N/A
STATIC COEFFICIENT Vs. SPEED:	____	PASS	____	____	____	____	N/A
ENERGY LIMIT:	____	PASS	____	____	____	____	N/A
TOTAL WEAR:	____	.013	____	____	____	____	N/A
WEAR LIMIT:	0.03	0.04	0.07	0.07	0.07	0.04	N/A

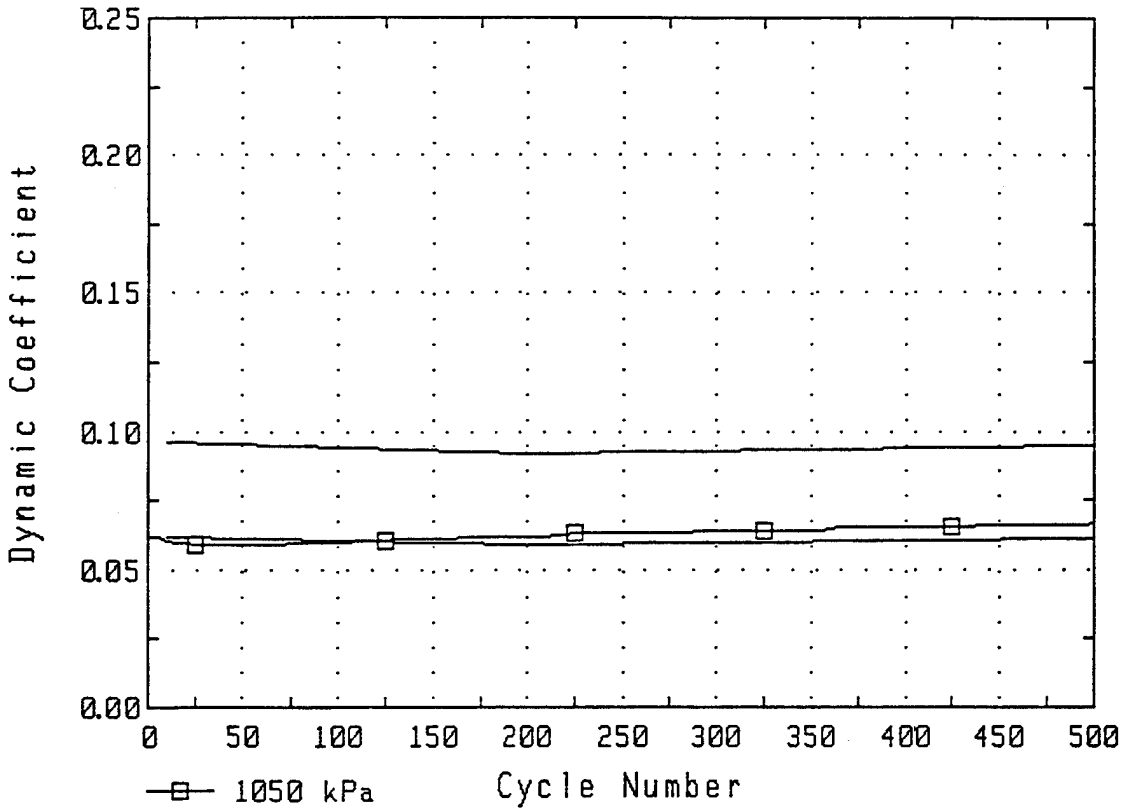
COMMENTS: None

N/A = Not Applicable

SwRI

"J" MACHINE OIL TEST LO-60264/AL-19660-L

Test name:	ARMYLAB
Test date:	03/20/92
Test description:	"J" MACHINE LO-60264
Oil type:	LO-60264/AL-19660-L
Viscosity:	SAE 30
Miscellaneous:	
Software version:	1.33
Run name & desc:	J0989044 - "J" MACHINE TEST RUN #1
Run date:	03/23/92
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	SAM J
Remarks:	"J" MACHINE OIL TEST RUN #1 LO-60264/AL-19660-L
Sequence name:	SEQ1220
Remarks:	Use 1Y0709 Disc and 8E4095 Plate
Number of cycles run:	1153
Machine:	J
Coast down check run:	03/09/92
Result:	67.61 seconds
Inertia check run:	03/09/92
Result:	0.9813 N-m-s»
Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	00001-26APO
Remarks:	SINTERED BRONZE
Plate name & desc:	8E4095 - Steel Plate
Surface:	0.70 to 1.00 micron Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	00001-26APO
Remarks:	.81 um. SURFACE FINISH
Report limit name:	LIM1220 - Reference run: J0989043
Limit file generated:	03/24/92
Report format name:	REP1220 - SINTERED BRONZE

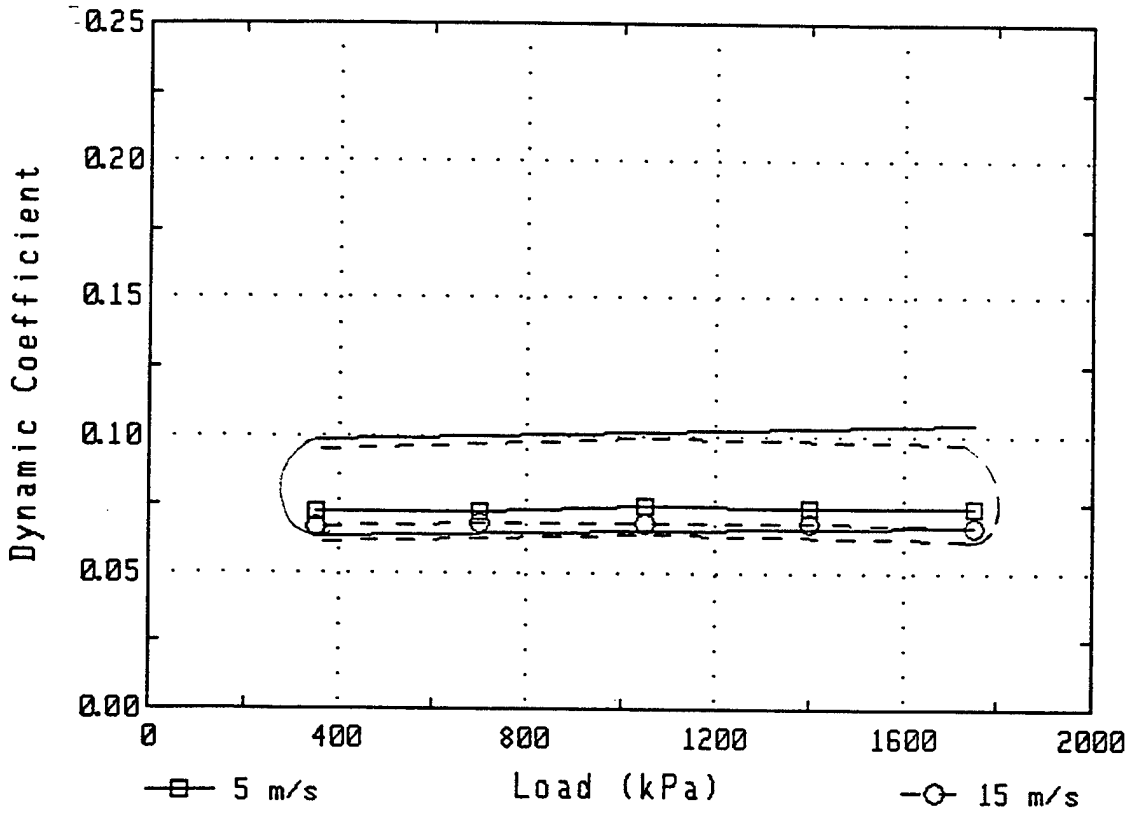


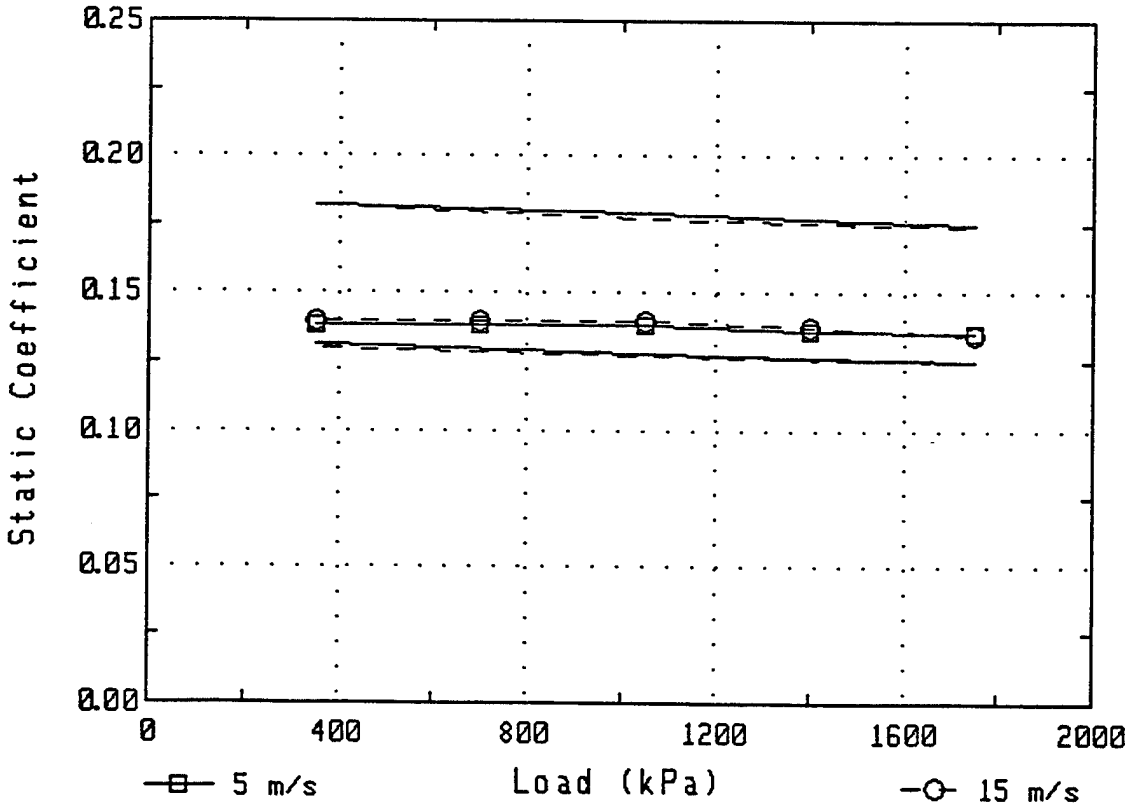
1Y0709 DISC
THICKNESS

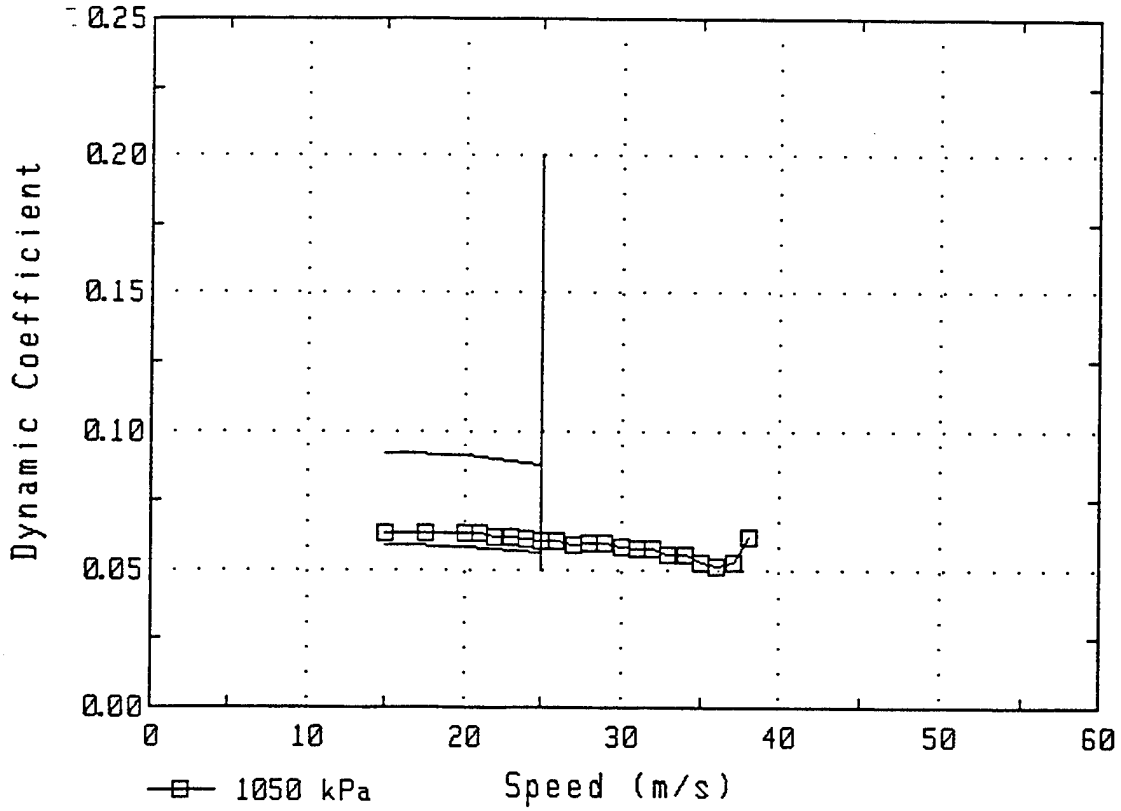
	Outer Diameter			Inner Diameter		
Loc	M1	M2	M3	M1	M2	M3
1	4.98	4.97	4.97	4.98	4.97	4.97
2	4.97	4.96	4.96	4.98	4.96	4.96
3	4.98	4.97	4.96	4.98	4.98	4.98
4	4.98	4.97	4.97	4.98	4.97	4.97
5	4.98	4.98	4.98	4.98	4.96	4.95
6	4.98	4.97	4.97	4.97	4.95	4.95
Avg	4.98	4.97	4.97	4.98	4.97	4.96

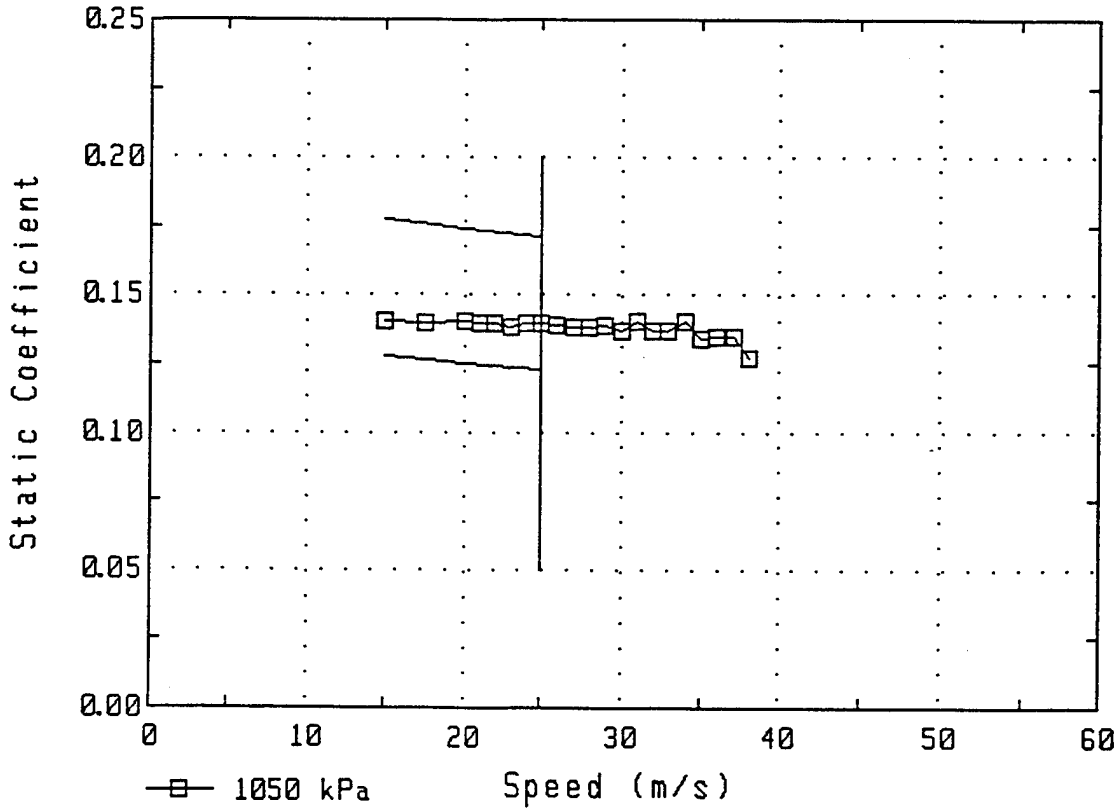
Compression set average wear: 0.011
M2 - M3 average Wear: 0.002

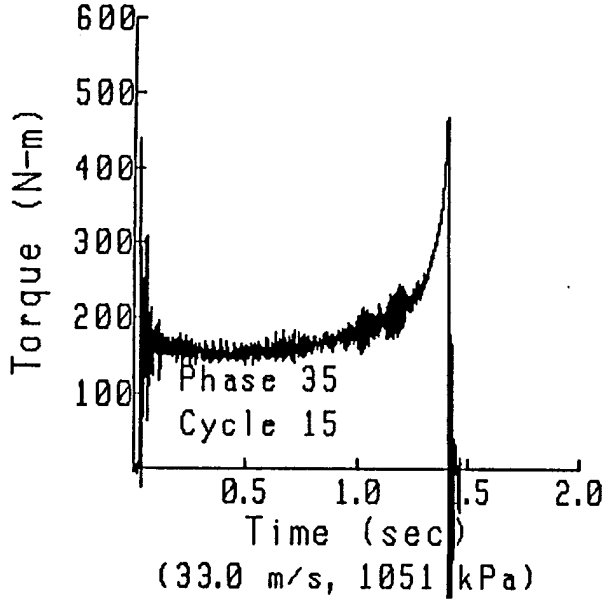
Total Wear (all measurements in mm): 0.013

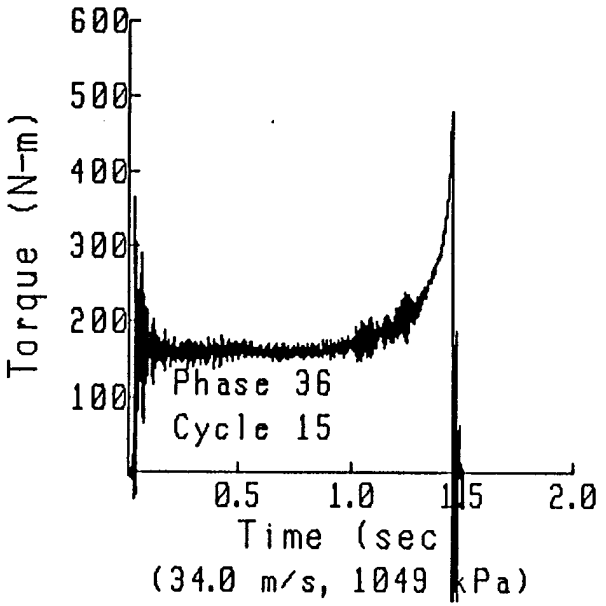

Dynamic Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
400
800
1200
1600
2000
5 m/s
Load (kPa)
15 m/s

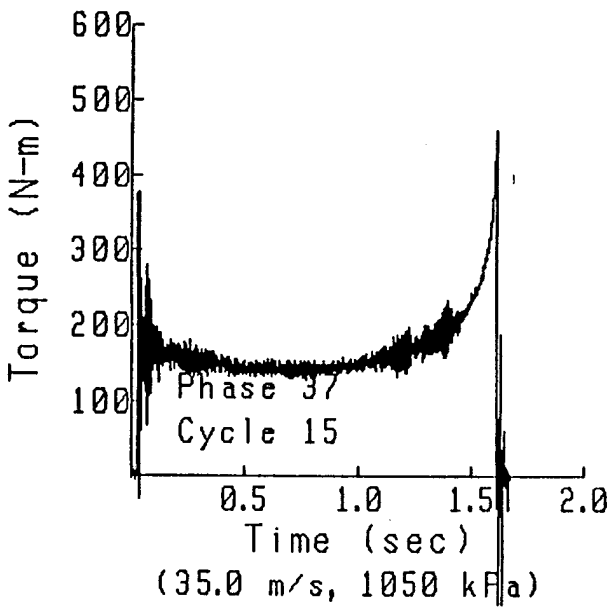

Static Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
400
800
1200
1600
2000
5 m/s
Load (kPa)
15 m/s

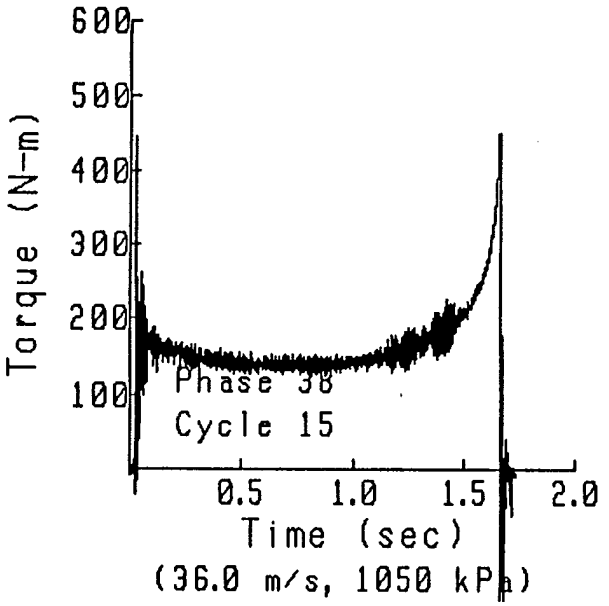

Dynamic Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)

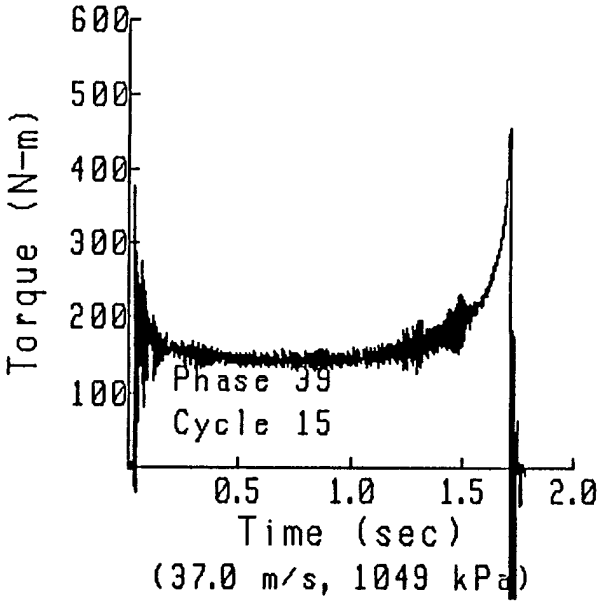

Static Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)

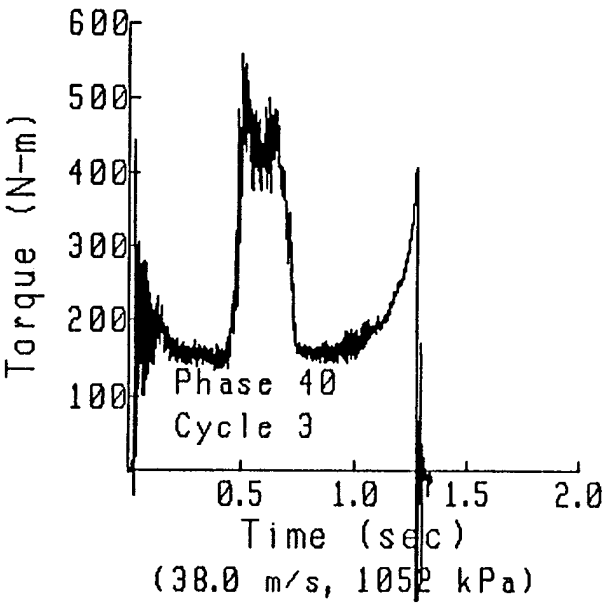

Torque (N-m)
600
500
400
300
200
100
Phase 35
Cycle 15
0.5
1.0
1.5
2.0
Time (sec)
(33.0 m/s, 1051 kPa)


Torque (N-m)
600
500
400
300
200
100
Phase 36
Cycle 15
0.5
1.0
1.5
2.0
Time (sec
(34.0 m/s, 1049 kPa)


Torque (N-m)
600
500
400
300
200
100
Phase 37
Cycle 15
0.5
1.0
1.5
2.0
Time (sec)
(35.0 m/s, 1050 kPa)


Torque (N-m)
600
500
400
300
200
100
Phase 38
Cycle 15
0.5
1.0
1.5
2.0
Time (sec)
(36.0 m/s, 1050 kPa)


Torque (N-m)
600
500
400
300
200
100
Phase 39
Cycle 15
0.5
1.0
1.5
2.0
Time (sec)
(37.0 m/s, 1049 kPa)


Torque (N-m)
600
500
400
300
200
100
Phase 40
Cycle 3
0.5
1.0
1.5
2.0
Time (sec)
(38.0 m/s, 1052 kPa)

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DGSC VC — 1
DGSC JBTB — 1
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RICHMOND VA 23297-5678

DIR DEFENSE ADV RSCH PROJ AGENCY
ATTN: ARPA/ASTO — 1
3701 N FAIRFAX DR
ARLINGTON VA 22203-1714

Department of the Army

HQDA
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REDSTONE ARSENAL
AL 35898-8060

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ARMY RSCH LAB
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2800 POWDER MILL RD
ADELPHIA MD 20783-1145

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21000 BROOKPARK RD
CLEVELAND OH 44135

CDR AMSAA
ATTN: AMXSY CM 1
AMXSY L 1
APG MD 21005-5071

CDR ARO
ATTN: AMXRO EN (D MANN) 1
RSCH TRIANGLE PK
NC 27709-2211

CDR ARMY SOLDIER SPT CMD
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NATICK MA 01760-5018

CDR ARMY INDUSTRIAL ENGRG ACTIVITY
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ROCK ISLAND IL 61299-6000

CDR ARMY WATERVLIET ARSN
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WATERVLIET NY 12189

DIR AMC LOG SPT ACT
ATTN: AMXLS LA 1
REDSTONE ARSENAL
AL 35890-7466

CDR APC
ATTN: SATPC L 1
SATPC Q 1
NEW CUMBERLAND PA 17070-5005

PETROL TEST FAC WEST 1
BLDG 247 TRACEY LOC
DDRW
P O BOX 96001
STOCKTON CA 95296-0960

CDR ARMY LEA
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NEW CUMBERLAND PA 17070-5007

CDR ARMY TECOM
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AMSTE TC D 1
AMSTE EQ 1
APG MD 21005-5006

PROJ MGR PETROL WATER LOG
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4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

PROJ MGR MOBILE ELEC PWR
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AMCPM MEP L 1
7798 CISSNA RD STE 200
SPRINGFIELD VA 22150-3199

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STECR LG 1
APO AP 96508-7850

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ARMY BIOMED RSCH DEV LAB
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FT DETRICK MD 21702-5010

CDR FORSCOM
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FT MCPHERSON GA 30330-6000

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ATTN: ATCD SL 5 1
INGALLS RD BLDG 163
FT MONROE VA 23651-5194

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FT KNOX KY 40121-5000

CDR ARMY QM SCHOOL
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ATCL MS 1
ATCL MES (C PARENT) 1
FT LEE VA 23801-6000

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FT SILL OK 73503

CDR ARMY TRANS SCHOOL
ATTN: ATSP CD MS 1
FT EUSTIS VA 23604-5000

CDR ARMY INF SCHOOL
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ATSH AT 1
FT BENNING GA 31905-5000

CDR ARMY ENGR SCHOOL
ATTN: ATSE CD 1
FT LEONARD WOOD
MO 65473-5000

CDR ARMY ORDN CTR
ATTN: ATSL CD CS 1
APG MD 21005

CDR ARMY ABERDEEN TEST CTR
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STEAC LI 1
STEAC AE 1
STEAC AA 1
APG MD 21005-5059

CDR ARMY YPG
ATTN: STEYP MT TL M 1
YUMA AZ 85365-9130

CDR ARMY CERL
ATTN: CECER EN 1
P O BOX 9005
CHAMPAIGN IL 61826-9005

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AMC FAST PROGRAM
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FT BELVOIR VA 22060-5818

CDR 6TH ID (L)
ATTN: APUR LG M 1
1060 GAFFNEY RD
FT WAINWRIGHT AK 99703

Department of the Navy

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NAVAL SEA SYSTEMS CMD
ATTN: SEA 03M3 1
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

CDR
NAVAL SURFACE WARFARE CTR
ATTN: CODE 63 1
CODE 632 1
CODE 859 1
3A LEGGETT CIRCLE
ANNAPOLIS MD 21402-5067

CDR 1
NAVAL PETROLEUM OFFICE
8725 JOHN J KINGMAN RD
STE 3719
FT BELVOIR VA 22060-6224

Department of the Navy/U.S. Marine Corps

HQ USMC
ATTN: LPP 1
WASHINGTON DC 20380-0001

PROG MGR COMBAT SER SPT 1
MARINE CORPS SYS CMD
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

PROG MGR GROUND WEAPONS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

PROG MGR ENGR SYS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

CDR
MARINE CORPS SYS CMD
ATTN: SSE 1
2030 BARNETT AVE STE 315
QUANTICO VA 22134-5010

Department of the Air Force

HQ USAF/LGTV
ATTN: VEH EQUIP/FACILITY 1
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

SA ALC/SFT 1
1014 BILLY MITCHELL BLVD STE 1
KELLY AFB TX 78241-5603

SA ALC/LDPG
ATTN: D ELLIOTT 1
580 PERRIN BLDG 329
KELLY AFB TX 78241-6439

WR ALC/LVRS 1
225 OCMULGEE CT
ROBINS AFB
GA 31098-1647

Other Federal Agencies

DOT
FAA
AWS 110 1
800 INDEPENDENCE AVE SW
WASHINGTON DC 20590

DOE
CE 151 (MR RUSSELL) 1
1000 INDEPENDENCE AVE SW
WASHINGTON DC 20585

EPA
AIR POLLUTION CONTROL 1
2565 PLYMOUTH RD
ANN ARBOR MI 48105